ITALIAN EXPEDITIONS TO THE KARAKORUM (K^2) AND HINDU KUSH

Prof. A. DESIO Leader

III - GEOLOGY - PETROLOGY

Volume I

GEOLOGY AND PETROLOGY OF HARAMOSH - MANGO GUSOR AREA

by

BRUNO ZANETTIN

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SCIENTIFIC REPORTS

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E. J. BRILL - LEIDEN

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PREFACE

The expedition to the Karakorum range which, during the summer of 1954 conquered K^2 (8611 m) — the second highest peak in the world — had, according to Italian tradition, a scientific as well as a mountaineering objective.

Besides the actual ascent, the programme of the expedition included research and study on the Geography, Geophysics, Geology, Anthropology and Ethnography of the area. Also, a small collection of specimens of local flora and fauna from elevated heights was occasionally made.

The expedition was carried out in three campaigns. A preliminary reconnaissance was made by Professor Desio with a guide (Mr. Riccardo Cassin), during the summer of 1953. The main stage followed in 1954 and lasted six months: it was carried out by an Italian team of five scientists (Professors Paolo Graziosi, Antonio Marussi, Bruno Zanettin, Ardito Desio and Dr. Guido Pagani, the physician of the expedition), eleven climbers and a photographer; a medical officer (Colonel Dr. M. Ata Ullah) and an assistant surveyor (Bad Shah Jan of the Survey of Pakistan), both from Pakistan, also joined the staff.

The scientific research was continued in the 1955 campaign which lasted about three months. The team this time consisted of three Italian scientists (Paolo Graziosi, Antonio Marussi and Ardito Desio) and three Pakistani assistants (Dr. N. M. Khan of the Geological Survey, Mr. M. Azizullah of the Survey of Pakistan, and Mr. Javed, a student at the University of Lahore).

The territory examined during the first campaign is to be found between the upper course of the Indus river, from Skardu as far west as the Stak valley, and the principal ridge of the Karakorum to the north. However, some reconnaissance was carried out westwards as far as Hunza and Gilgit and eastwards as far as Bagicha. The territory covered in 1955 lies between the Gilgit area and Chitral.

A new scientific campaign was organized by Professor Desio during the summer of 1961 in order to explore geologically the Wakhan territory, lying between the Hindu Kush and the Pamirs, and to extend eastwards the geophysical observations. The leader was accompanied by Professor Marussi and two assistants (Dr. Giorgio Pasquarè and Dr. Ercole Martina) and by an Afghanistan geologist (Mr. Ajruddin).

Whereas the geophysical programme was carried out in its entirety, the geological one was reduced to the survey of Central Badakhshan, for the expedition was not allowed to cover Wakhan.

In order to complete the geological research over an area which had been omitted from the itineraries of previous expeditions and to clear up a number of unsolved problems of its stratigraphical geology, Prof. Desio, accompanied by two assistants (Dr. Ercole Martina and Dr. Roberto Galimberti) organized in 1962 a further campaign to the Western Karakorum. The territory covered this time is to be found between the Chogo Lungma and the Sosbun glaciers, and the upper valley of the Hunza river.

The present volume deals with the geological and petrographical results obtained by the 1953-1954 expedition into the region comprised between the Haramosh and the Mango Gusor groups, i. e. between the Indus river from Skardu as far as the Stak junction, and the watershed of the Koser Gunge — Mango Gusor ranges, northwards of the Shigar valley. This region was partially (Shigar valley) examined from the geological point of view by A. Desio during the 1929 Italian Expedition to the Karakorum and partially (the Stak, Tourmik and Shigar valleys) during the 1953 expedition. No reports have yet been published about the results obtained in this region. During the 1954 expedition prof. Zanettin was charged to carry out detailed studies on the Geology and Petrology of the valleys of Stak, Turmik and Shigar, in order to complete and draw up the preliminary results of my previous journeys. Zanettin devoted himself with great accuracy to his task: the present volume contains the main result of his work.

This is not the place to point out the value of Zanettin's contribution to the geological study of the Western Karakorum range, nor to summarize the results attained by him. I shall have other occasions to recall his collaboration, since Zanettin was associated with me in the geological exploration of the Baltoro valley during the 1954 expedition and also collaborated in the petrological study of the samples which I collected during the 1953 and 1954 campaigns.

Before concluding this short preface, I would like to thank Professor Zanettin for his effective and diligent collaboration during the 1954 expedition and afterwards. I also wish to thank the Italian Consiglio Nazionale delle Ricerche which financed our expeditions to the Karakorum and Hindu Kush and made it possible to publish the present volume.

Ardito Desio

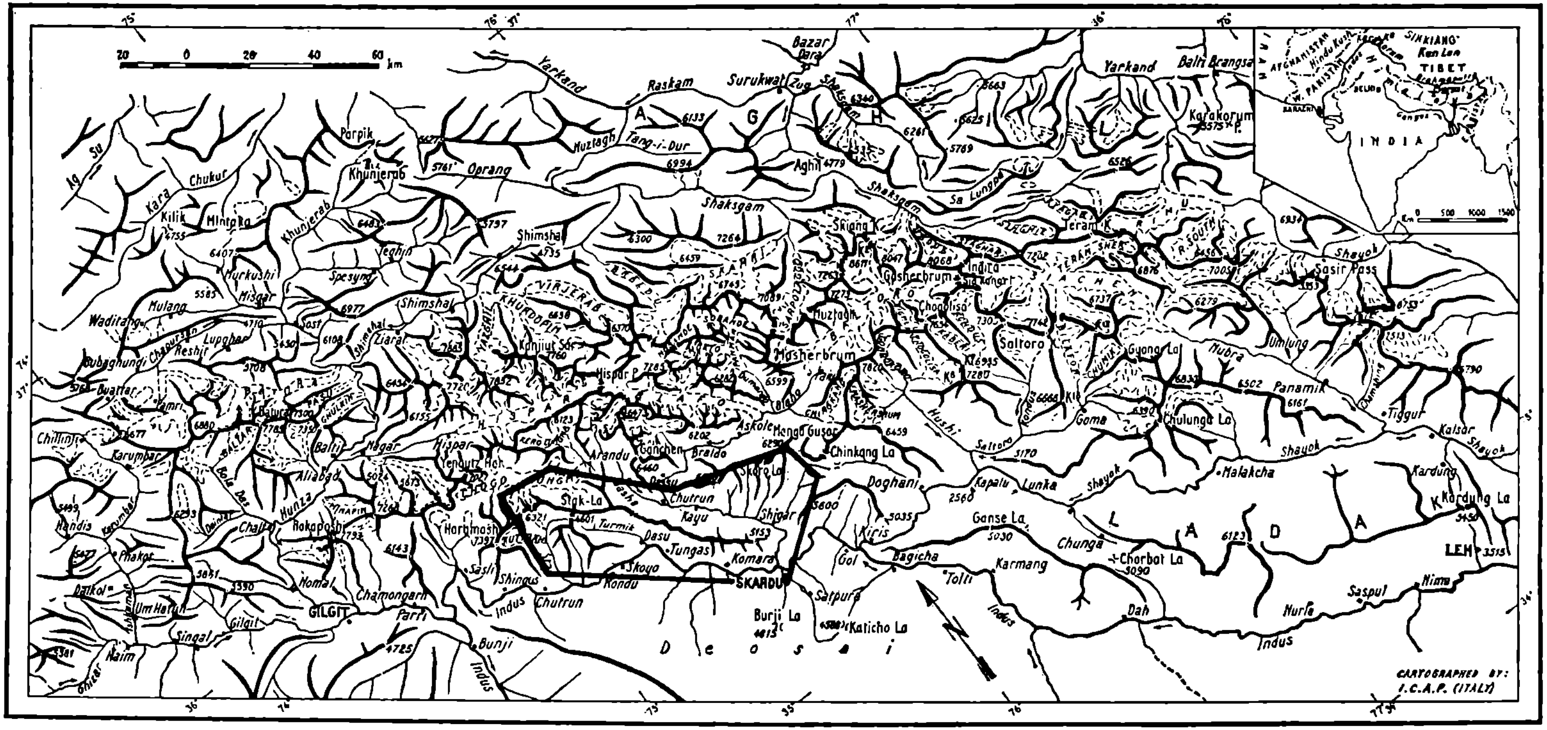

Fig. 1 - Orographic sketch-map of the Karakorum range.
The Haramosh - Mango Gusor area is limited by red line.

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FOREWORD

This work is concerned with that portion of the central southern Karakorum lying between the Haramosh group (7397 m; 24,270 ft) and the Mango Gusor (6290 m; 20,630 ft) which rises from the ridge separating the valley of the Shigar from that of the Braldu. This is the most southerly part of the territory mapped in 1954 by the Italian Expedition to Karakorum-K² which was led by A. Desio (fig. 1).

All the area lying west of the Basha-Shigar basin was completely unknown before the beginning of the survey work of our 1954 expedition. Only A. Desio (the preceding year (1953)) had traversed it going from Skardu to the Stak valley, crossing the Stak-la, and reaching the upper basin of Shigar valley passing through Ganto-la. In the course of this excursion he made the first geological observations of that particular region and put together the first elements of a geological map. He did not publish any of these observations, however, but at the start of our geological survey of 1954 he very kindly gave me all the data, map and material in his possession to direct my attention to particular features and to lighten the burden of detailed field work.

The presentation of the data gathered in the field or deduced from petrographic and chemical study will follow a topographic sequence. Firstly, the westernmost area will be described, then those areas which lie further and further to the east. The following is the order: Stak basin, Askore-Twar basin, Skoyo-Turmik zone, Turmik-Indus basin, and Shigar basin (fig. 2).

In making the subdivision into the several zones the distinctive geological and petrographic features displayed by certain of these zones have, of course, been a prime consideration: so, between the contiguous basins of Twar and of Turmik another zone (Skoyo-Turmik) has been introduced because here a plutonic mass of particular type occurs; similarly the rocks of the Shigar valley are dealt with in separate paragraphs since on its two opposite sides there occur two different types of formations.

On the other hand, since some formations are common to several zones, the general discussion of their characteristics is to be found in the chapter dealing with the zone where these formations assume greatest importance either for their areal extent or because their manifestations are specially conspicuous; similarly the general discussion of the geology and petrography of the metamorphic formation, which occurs in the area between the Askore valley and the Braldu valley (involving several of the zones) has been deferred until the final paragraph of the chapter concerned with the Turmik valley, where as it happens rocks of this type are very well represented.

Each chapter contains two parts: in the first part there is a comment on the geological conditions of the several formations, and a summary of the results obtained by the petrographic and chemical analyses of field material; in the second part there are conclusions as to the chemical composition of the rocks, and to the conditions which prevailed during the formation of these rocks, and some comparisons with other Himalayan zones known to be geologically similar.

The final chapter is a synthesis, an attempt to set out the whole sequence of geological and petrological events in the region.

ACKNOWLEDGEMENTS

I would like to thank Prof. Luigi Meneghello of the University of Reading, and all those, too numerous to mention, who worked so hard and conscientiously under his direction to translate this work from the Italian.

My sincere thanks go also to Dr. Carla Adami Fort, who translated the petrographical descriptions.

Fig. 1 - The Haramosh group (view from south-east).

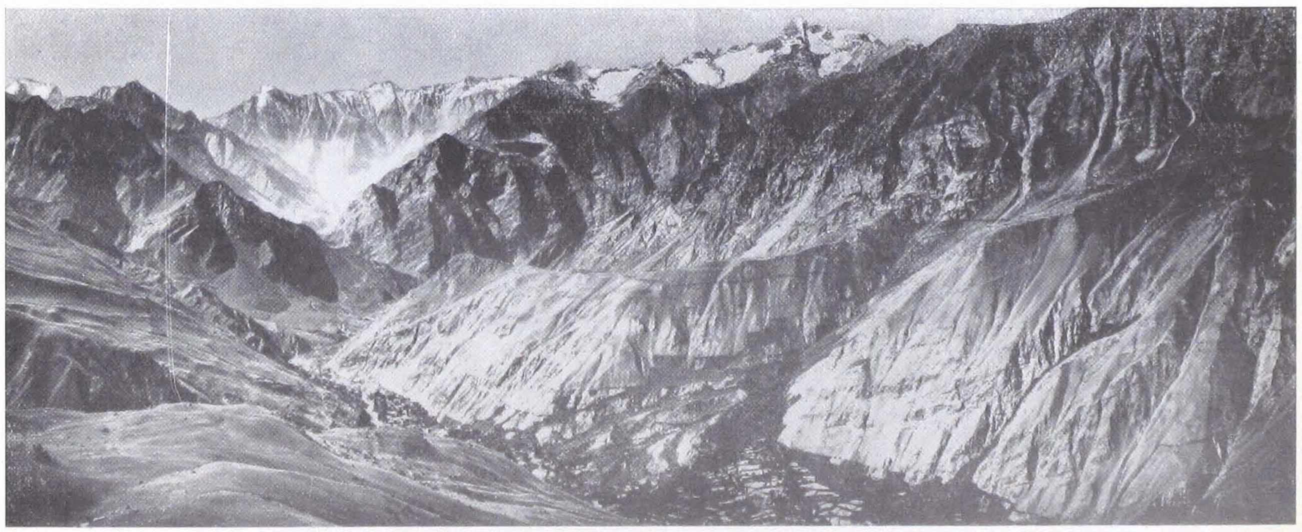

Fig. 2 - The lower Turmik valley, near the confluence with the Indus river. On the right side of the valley the plagioclase gneisses of the Skoyo-Turmik mass outcrop over the moraine.

Fig. 3 - The middle and upper Turmik valley.

(Photo F. Lombardi - Istituto Geogr. Milit.)

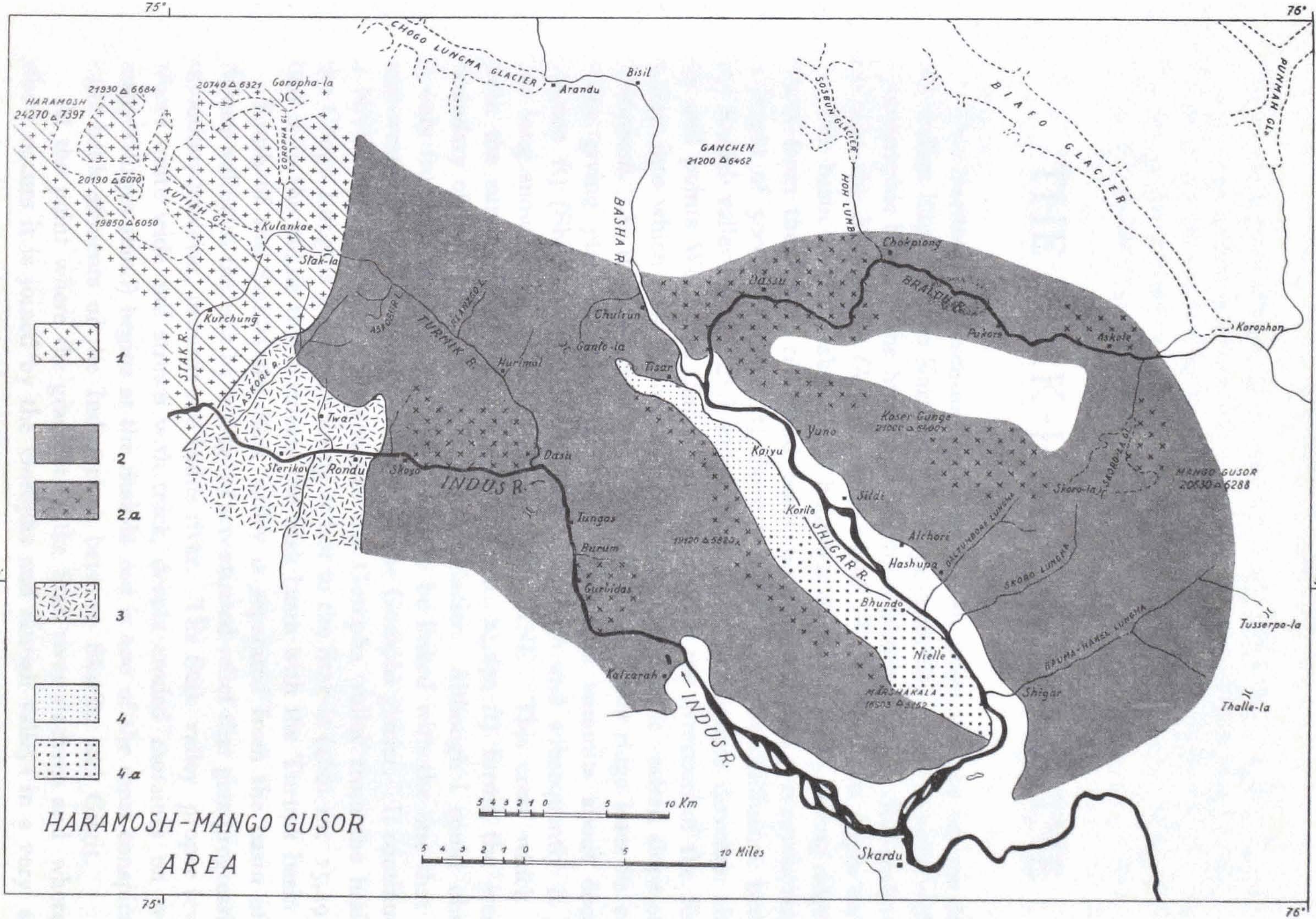

Fig. 2 - General geological sketch-map of the Haramosh-Mango Gusor area.
1 - Migmatites with pre-Cambrian paleosome. 2 - Metamorphites derived from Cretaceous volcanic-sedimentary rocks. 2a - Id. feldspathized or granitized. 3 - Hypersthene diorites. 4 - Tonalites. 4a - Diorites, gabbrodiorites and amphibole gabbros.

I

THE STAK-HARAMOSH ZONE

This territory, representing the westernmost point reached by me during the Italian Expedition to Karakorum in 1954, coincides almost exactly with the hydrographic basin of the Stak river which, in addition to the *Stak valley* also includes the *Kutiah* and *Gorophu valleys* both of which join its upper section.

The basin of the Stak river is bounded on the west by a long ridge that starts from the Indus river and leads northwards, rising progressively to a height of 5000 m (16,500 ft) above sea level near the confluence between the Kutiah valley and the Stak valley. Here the ridge changes direction abruptly and points WNW, so that it runs parallel to the direction of the Kutiah valley into which flow the great glaciers which cover the eastern slope of the *Haramosh.* As it approaches the Haramosh group, this ridge loses its continuity giving place to a number of well defined summits about 6000 m (20,000 ft) (Shinka Mashkila; Korang Kar) high and subsequently it joins the long snowy crest running roughly SSW-NNE. This crest which runs from the summit of the Haramosh (7397 m; 24,270 ft) forms the western boundary of the high basin of the Kutiah glacier. Although I could observe it only from a distance, this crest seems to be linked with the one that runs east-west and blocks the upper basin of the Goropha glacier. It continues in a NNW-SSE direction and separates the Goropha valley from the basin of the Chogo Lungma glacier declining at last to the Stak-la (4601 m; 15,491 ft) that is to the saddle that connects the Stak basin with the Turmik basin.

South of the Stak-la the Stak valley is separated from the basin of the Askore valley to the east by a ridge of accentuated relief that gets progressively smoother, however, towards the Indus river. The Stak valley proper (everywhere quite wide and strewn with thick, deeply eroded moraines on which many villages stand) begins at the Stak-la and is one of the most conspicuous right-bank affluents of the Indus river between Skardu and Gilgit.

At the point where the gradient of the Stak river slackens and where an elbow occurs it is joined by the Goropha and Kutiah valleys in a very short distance. The first runs from the north and the second from the north-west. The area in which the three rivers unite is called Kulankae.

The Gorophа valley is divided throughout its length by a very accentuated medial moraine. In the lower part of the valley this separates the pastures of the eastern side from the glacial tongue (covered by abundant wastes) that lies on the opposite slope.

The upper basin of this valley is occupied by a broad glacier and communicates with the Chogo Lungma glacier basin across a saddle at about 5000 m (16,500 ft) which has been called Gorophа-la (1).

The Kutiah valley is completely occupied by a glacier that came into existence in 1953 (2), and whose snout at the time of my observations stood about one kilometre downstream of the confluence with the Stak valley.

To summarize the foregoing, it can be said that the zone is limited on the south by the two sides of the lower and middle Stak valley, but, to the north it expands, opening like a fan in the direction of the upper basin of the Stak (east), of the Gorophа valley (north) and of the Kutiah glacier (north-west). In the course of many excursions, the writer has covered the whole of this area with the exception of the upper of the Kutiah glacier (corresponding to the imposing and impracticable eastern wall of the Haramosh) and the extreme part of the upper basin of the Stak valley (that is the Stak-la zone) inaccessible, at that time, by a caravan of porters on account of the great quantity of snow which had accumulated on that pass. Fortunately, the year before (1953), A. DESIO made a geological sketch-map of the Stak-la zone; I have inserted it in the geological map reproduced in fig. 3. In general, no field observations in the Stak basin were possible at heights above 4000 m (13,250 ft) because of the existence of abundant snow during the time spent there. It can be said, however, that the rocks occurring at higher levels are sufficiently well known from indirect observations and from the detrital material that has come down from them.

The rocks occurring in the Stak basin belong to a unique geological formation and everywhere display many similar petrographic characteristics; they are migmatitic gneisses in which the paleosome is represented by gneissic micaschists or biotite-kyanite-garnet paragneisses, and the neosome by quartz-feldspar gneisses fairly rich in garnet and of aplitic aspect.

Studying the petrographic descriptions of the different samples collected

(1) Gorophа-la was reached for the first time by PROF. A. MARUSSI and CAPT. F. LOMBARDI, members of the Italian Expedition to Karakorum 1954.

(2) For an account of the formation of this glacier, see A. DESIO, 1953, 1954.

it can be seen that there is no rock from the right side of the Kutiah glacier, though in another part of this book the author speaks about rocks found there. I shall explain that on the side of this valley a collection of the most significant specimens had been made; but, through a succession of unfavourable circumstances, these were abandoned in crossing the Kutiah glacier.

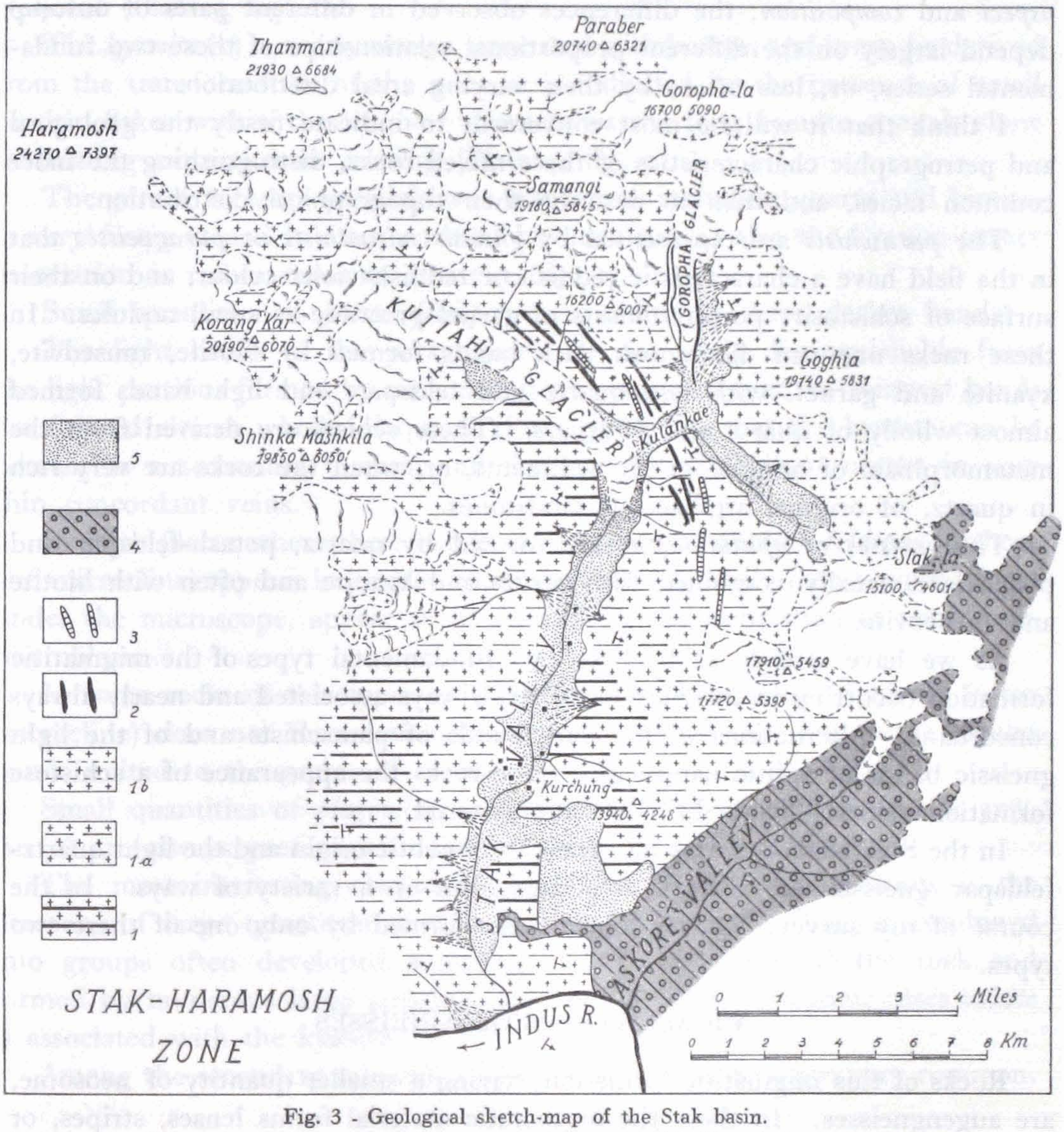

Fig. 3 - Geological sketch-map of the Stak basin.

1, 1 a, 1 b - Migmatites with pre-Cambrian paleosome:

1 - Migmatitic augengneisses;
1 a - Migmatitic banded gneisses;
1 b - Migmatitic granitic and pegmatitic gneisses;

2 - Amphibolites of the pre-Cambrian formation;
3 - Marbles, calciphyres and hornfelses of the pre-Cambrian formation;
4 - Garnetiferous amphibolites of the Cretaceous formation;
5 - Moraine, alluvium and debris.

GEOLOGICAL CONDITIONS AND PETROGRAPHIC FEATURES

The whole of the Stak zone is developed in *migmatites* consisting of an intimate association of *paraschists of pelitic origin* and of *gneisses of aplitic aspect* and *composition*; the differences observed in different parts of outcrop depend largely on the different proportional relationships of these two fundamental series, or, less often, by their varying areal distribution.

I think that it will be most convenient to indicate firstly the geological and petrographic characteristics of these mixed rocks, distinguishing the more common facies, and then to describe their topographical distribution.

The *paraschists* are represented by *gneissic micaschists* or *paragneisses* that in the field have a characteristic reddish or reddish-violet colour, and on their surface of schistosity porphyroblasts of garnet protrude as small nodules. In these rocks one can distinguish dark bands formed by biotite, muscovite, kyanite and garnet, with less quartz and feldspars and light bands formed almost wholly of quartz and feldspars. These schists are derived from the metamorphism of original pelitic sediments, or, when the rocks are very rich in quartz, of original argillaceous sandstones.

The *gneisses of aplitic aspect* are formed by quartz, potash-feldspar and plagioclase usually combined with garnet and kyanite and often with biotite and muscovite.

As we have already said, these two fundamental types of the migmatitic formation occurring in the Stak basin, are always associated and nearly always concordant. Alternations of the dark bands of paraschists and of the light gneissic bands of aplitic nature give these rocks the appearance of a schistose formation veined "lit-par-lit" by sialic material.

In the Stak basin the dark paragneisses of pelitic origin and the light quartz-feldspar gneisses are always associated, but in a variety of ways. In the course of my survey, I never found rocks formed by only one of these two types.

MIGMATITIC AUGENGNEISSES

Rocks of this migmatitic formation, having a smaller quantity of neosome, are augengneisses. In these the leucocratic material forms lenses, stripes, or concordant thin layers; often the feldspathic or quartzose-feldspathic material forms porphyroblasts which are sometimes united by very thin streaks (Plate 1, figs. 1 and 2). The paleosome is represented by pelitic paragneisses with light and dark bands of different thickness warped by garnet porphyroblasts or feldspathic lenses (54 PZ-28).

The *dark bands* are formed by *biotite, kyanite* and *garnet* and by different amounts of *muscovite*; this is more rare when associated with the above mentioned minerals but more abundant where the sialic minerals become more frequent (Plate 3, fig. 1).

The *kyanite* (1) is nearly always associated with biotite, and it can be derived from the transformation of the mica as is indicated by the presence of small biotitic flakes within the kyanite. Sometimes the long kyanite crystals show undulating extinction or curving (Plate 4, fig. 3).

The *garnet*, in large poikiloblastic fragments, including quartz and biotite, is very frequent and is often covered by mica flakes; also the kyanite-garnet association is rather common (Plate 3, fig. 1).

Small quantities of *potash-feldspar* are present in these darker bands.

The light bands of the paragneisses are not easily distinguishable from the light portions formed by neosome; it was observed that the thinnest bands are formed almost wholly of quartz (Plate 3, fig. 3), that the kyanite can be present as a secondary mineral and that the potash-feldspar occurs in very thin concordant veins.

In some places where these bands are enlarged, the *potash-feldspar* (orthose and microcline) appears in greater quantities and eventually forms *augen* which, under the microscope, appear to be formed by the association of many porphyroblasts.

In some rocks of this type, on the other hand, the potash-feldspar (often microcline) does not form lenses or large porphyroblasts, but forms regular bands united to the grains of quartz.

Small quantities of *plagioclase* corresponding to oligoclase-andesine 30% An (2) are always present with the orthoclase (or microcline).

The most interesting characteristic shown by these sialic bands is the presence of large quantities of *kyanite* (Plate 3, fig. 2). This is combined into groups often developed according to the schistosity of the rock and formed by numerous large poikiloblasts (Plate 3, fig. 2). In some cases *zoisite* is associated with the kyanite.

Among the secondary minerals, yellowish grains of *rutile* are very common.

(1) The kyanite is often twinned on (100). The extinction angle on (100) is about 30°.

(2) $\varepsilon_{quartz} > \alpha' \geq \omega_{quartz}$; $\varepsilon_q > \gamma' > \omega_q$. The maximum extinction angle measured in the zone ⊥ (010) of albite twins = 12° — 15° = 28% — 32% An; in rare cases the determinations under U.S. give 18° — 20° = 35% — 37% An.

A chemical analysis has been made of a representative sample of the type of rock now described. This sample was taken in the lower Stak valley about two kilometres down-stream of the village of Kurchung. The weight percentages are shown in Table 1, together with the corresponding NIGGLI's values.

TABLE 1

Biotite-kyanite-garnet paragneiss with feldspathic lenses and beds; *lower Stak valley* (54 PZ-28).

CHEMICAL COMPOSITION
(Analyst: B. Zanettin)

SiO_2	62.72%	MgO	1.66
TiO_2	1.61	CaO	0.44
P_2O_5	0.12	Na_2O	1.08
Al_2O_3	18.86	K_2O	3.39
Fe_2O_3	1.17	H_2O+	1.55
FeO	6.91	H_2O-	0.34
MnO	0.07		
			99.92

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Biotite-kyanite-garnet paragneiss	262	46.4	38.1	2	13.4	0.67	0.27	0.05

As one could foresee, this rock does not correspond with any "magmatic types" proposed by P. NIGGLI.

Rocks of this type are easily distinguished in the field by their reddish colour and by the presence of small nodules on the surfaces of schistosity. These rocks are common near the mouth of the Stak valley (alternating with particular types of rocks which I shall discuss later), and form the most common facies throughout the lower Stak valley south of the village of Kurchung on both the right and left flanks. On the right side, the types that have less neosome occur at heights above 3500-4000 m (11,500-13,000 ft), while lower down the lighter gneisses, similar to those which will be described below, are most common.

It is also fairly easy to find this type of paragneisses in other places, but they are always limited in extent and are surrounded by rocks with different characteristics.

Other rocks, which have quantities of paleosome and neosome like those described above, are characterized by the complete absence of kyanite, by the scarcity of potash-feldspar and by the abundance of quartz and of plagioclases 35-37% An; also abundant are biotite, muscovite and garnet (54 PZ-48, 48a).

Rocks of this last type, interlayed with kyanite-paragneisses, have been observed only in the zone called Kulankae.

MIGMATITIC BANDED GNEISSES

With increasing leucocratic material, the augengneisses grade into *migmatitic banded gneisses*. To this group belong rocks in which the quantitative ratio between the light and dark portions can be very different, but all are similar in appearance and petrographic characteristics, as a result of the similarity with which paleosome and neosome combine, penetrate and interact.

The first and the most evident common characteristic of all the rocks of this group is the regular alternation of light aplitic bands with dark pelitic bands (Plate 1, fig. 4). These bands which vary in thickness from a few millimetres to a few decimetres seem clearly distinguishable, but closer observation shows that the paleosome is closely penetrated by the neosome and vice-versa, and that evanescent streaks of minerals of the paleosome persist in the neosome.

It can also happen that locally the light-coloured and dark bands are not easily distinguishable and that dark discontinuous evanescent streaks of micas parallel to the schistosity of the formation, go through lighter-coloured rock (Plate 2, fig. 2); in such cases a thick layer of greyish colour is interposed with the more common banded gneisses.

The *dark bands* of the paleosome correspond to paraschists of pelitic origin, as it is demonstrated by the close similarity of mineralogical composition between these and the augengneisses occurring in the lower branch of the Stak valley. In these cases the essential components are again *biotite*, *muscovite*, *kyanite* and *garnet* in variable proportions (54 PZ-32). The two types of micas are nearly always associated, biotite being the most prevalent; while, however, the *muscovite* is always perfectly bedded with the schistosity, some flakes of biotite may be disposed transversely or perpendicularly to the planes of schistosity. The kyanite can be present either in isolated crystals or in swarms of many particles and the garnet, which is fairly abundant, appears in crystalloblasts of very variable size. Grains of *rutile* represent a common associated mineral. Most of the *light bands* (54 PZ-29) are formed by quartz and feldspars. The quartz, in particles developed and lengthened according to the schistosity of the rock, forms depressed flattened lenses, which are very extended and here and there pinched; they alternate concordantly with the more conspicuous layers which are formed by the association of rather small crystals of *potash-feldspar* (1) (modifications *orthoclase, microcline* and *sanidine*) of *plagioclases* 20-30% An (2) and by a smaller quantity of quartz grains (Plate 3, fig. 4).

Here and there the potash-feldspar, or more exactly, *microperthite* (and *microclineperthite*) is exceptionally well developed, forming porphyroblasts that grow and replace the quartz-feldspar-rich matrix; in fact they have irregular boundaries and enclose within their borders numerous quartz grains (Plate 4, fig. 1 and 2). Quartz grains are present less frequently in the inner parts of these microperthite porphyroblasts.

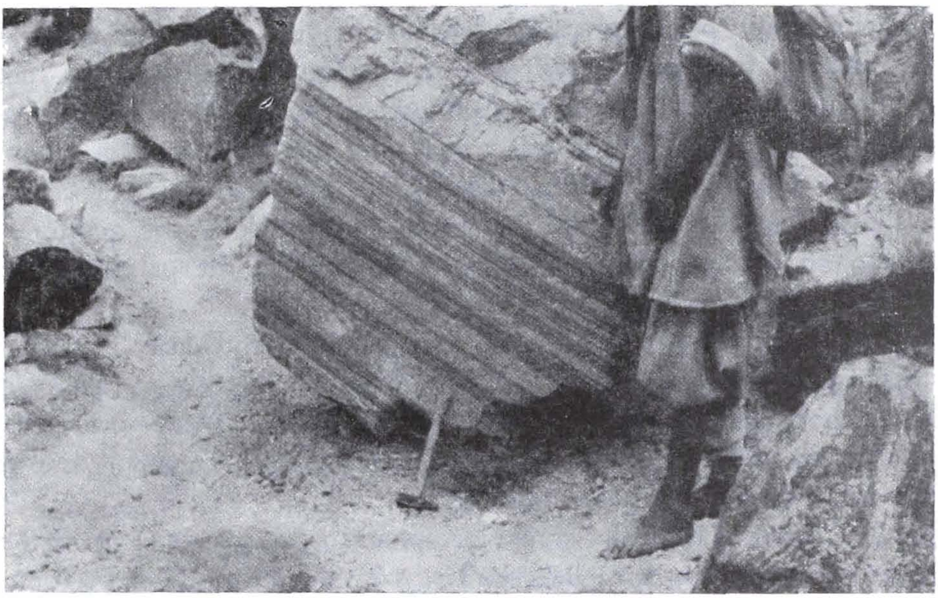

Fig. 4 - Migmatitic gneisses of middle Stak valley; the dark and light bands are quite parallel.

In some rare cases the porphyroblasts are formed by plagioclase. This has been observed only in the upper Stak valley, above Kulankae. *Myrmekite* is sometimes formed between potash-feldspar and plagioclase.

It is noticeable that these feldspars have a definite disposition in the rock; whilst determining the optical orientation of some potash-feldspar crystals, I have observed that the n_β direction lies in a plane which is almost perpendicular to the schistosity surface.

(1) The size of $2V\alpha$ for many K-feldspar crystals ranges from 58° to 68°; more rarely $2V\alpha = 72° — 74°$. Few individuals, characterized by very neat cleavage, have a very small optic angle ranging from 0° to 20°.

(2) $\alpha' \geq \omega_q$; $\varepsilon_q > \gamma' > \omega_q$. The maximum extinction angles measured in the zone ⊥ (010) of albite twins = 2° — 12° = 21 — 30% An.

The sialic bands, always formed by quartz and feldspars, also contain, in greater or lesser quantities, the minerals constituting the dark bands of paragneisses, that is *biotite*, *muscovite*, *kyanite*, *garnet*; the last two minerals are nearly always present, and in some cases in larger quantities than in the dark pelitic bands.

It is noticeable that kyanite is never present in the leucocratic bands which are interbedded with paraschists devoid of kyanite.

As it has been said, the presence in the leucocratic bands of streaks of minerals characterizing the paleosome is one of the most evident and typical macroscopic characteristic of these banded gneisses.

A chemical analysis has been made of a sample taken from a thick sialic band. The weight percentages are shown in Table 2, with the corresponding NIGGLI's values. These results show that the rock corresponds to the engadinite-granitic type of the leucogranitic magmas.

TABLE 2

Leucogranitic gneiss with biotite, garnet and kyanite; *middle Stak valley* (54 PZ-29).

CHEMICAL COMPOSITION

(Analyst: B. Zanettin)

SiO_2	72.52%	MgO	0.06
TiO_2	tr.	CaO	1.35
P_2O_5	0.28	Na_2O	3.62
Al_2O_3	14.75	K_2O	4.72
Fe_2O_3	0.06	H_2O+	0.26
FeO	2.08	H_2O-	0.24
MnO	tr.		
			99.94

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Leucogranitic gneiss with biotite, garnet and kyanite	391	46.8	10.2	7.8	35.2	0.46	0.47	0.76
Engadinite-granitic type (leucogranitic magmas).	380	43	13	8	36	0.5	0.25	

Basis				*Molecular Norm*	
Q	55.5	Q	= 55.5	Q	26.1
Kp	16.9	L	= 39.7	Or	28.2
Ne	19.7	M	= 4.2	Ab	32.8
Cal	3.1	M'	= 4.8	An	5.2
Sp	0.2	π	= 0.08	Cord	0.4
Hz	2.9	μ	= —	Fe-Cord	5.3
Fs	0.1	γ	= —	Hy	1.2
Fa	1.0	α	= 20.74	Mt	0.2
Cp	0.6			Cp	0.6

The transition from the mica-kyanite-garnet paragneisses to the quartz-feldspar bands is never abrupt, but is generally very gradual. It should be made clear that a layer formed only by quartz is interposed between the light and dark bands.

Passing from the central part of the dark band to the central part of the sialic band, one observes some variations that can be very briefly described: in the mica-kyanite-garnet bands (similar to those of the augengneisses) quartz-feldspar streaks appear. At first these are very thin and rare, but later they become thicker and more and more numerous and eventually become predominant in the paleosome. At the same time the micaceous material forms increasingly thinner and more discontinuous bands and eventually evanescent streaks in which the muscovite is more frequent than the biotite. Sometimes the micas totally disappear in the central parts of the light bands whilst kyanite and garnet nearly always remain, and can be of greater dimensions here than in metamorphic pelitic bands (Plate 2, fig. 1).

In those cases (rather rare and confined to small portions of the rock) in which the transition between the dark material of pelitic origin and light material of granitic composition does not occur across but along the strike, it can happen that a dark band formed by numerous parallel mica-kyanite-garnet rich layers loses its unity and breaks up, as if a part of it has been taken away and replaced by sialic material. Only a few dark layers continue into the light material and these subdivide into increasingly thinner branches disposed along the same line (Plate 1, fig. 3); thin swarms of kyanite and garnet unite the different branches and persist as relics of the pelitic bands after the disappearance of micaceous minerals.

MIGMATITIC GRANITIC, APLITIC, PEGMATITIC GNEISSES

Gneisses of the migmatitic types are *richer in neosome*; however, since in all the Stak rocks the paleosome is never absent, these types must be considered to be associated with the migmatitic banded gneisses in terms of transition; and that is what one in fact observes in the field. In this group, therefore, are classified all those rocks in which the leucocratic component (over 3/4) is predominant. For the most part these rocks too are migmatites with parallel bands, but the light bands are particularly thick and abundant; whilst the dark micaceous bands, although rare and thin, always show a surprising longitudinal extension.

These rocks have a mineralogical composition and petrographic and textu ral characteristics which are perfectly analogous to those of the migmatitic banded gneisses.

In other cases the leucocratic bands are *coarse-grained* and sometimes represent real *pegmatitic gneisses* (54 PZ-40) easily recognizable on the field by reason of the abundance of tourmaline in them (Plate 2, fig. 3).

However, apart from the presence of tourmaline, the mineralogical composition of these pegmatitic facies is similar to that already observed in the leucocratic portions of the migmatitic banded gneisses: quartz, feldspars and, in lesser quantities, kyanite and garnet. The quartz, in large particles, forms some flattened lenses according to the planes of schistosity whilst the *feldspars* are scattered in a uniform way and are formed of similar sized particles. The large feldspathic porphyroblasts typical of the great majority of the sialic rocks mentioned above are therefore missing. The potash-feldspar (1) is represented by *orthoclase*, but *sanidine* is also present. The plagioclase (2) is *oligoclase* 15-20% An.

Tourmaline (schorlite), and also *almandine*, appear well developed in individual poikiloblasts.

The *kyanite*, always occurring as streaks of crystals parallel to the schistosity of the rock, is often partially altered into *muscovite*; the alteration proceeds from the periphery towards the centre and sometimes only small crystals of kyanite, in the centre of the micaceous aggregate, remain (Plate 4, fig. 4). Such processes of alteration, seen only in these more sialic gneisses, give reason to believe that quite a large proportion of the light micas existing in these rocks have been formed in similar way.

Moreover, in the feldspathic crystals of the coarse-grained rocks there is more evidence than in other types of the presence of very small needles of unknown composition which may be orientated along particular planes of the host material. These are often accompanied by slightly more developed prismatic-lengthened crystals comparable to kyanite.

More rarely the *granitic gneisses* form masses instead of bands. These are always of small extent and always include fairly long stretches of paraschists.

These rocks (54 PZ-52) besides having a coarser grain than those that constitute the common leucocratic bands of the migmatitic formation, are also devoid of the frequently occurring biotitic streaks (Plate 2, fig. 4). Their

(1) $2V\alpha$ oscillates around 60°; some of the individuals show $2V\alpha$ close to 20°.

(2) $\gamma' \equiv \omega_q$; negative optic sign, but sometimes positive. By the U.S. small extinction angles of albite twins measured in the zone $\perp$ (010): 0° — 6° = 15 — 20% An.

fundamental mineralogical composition has been already described (1); the only remarkable characteristics are the absolute predominance, between the micas, of muscovite, derived partly from the alteration of biotite (present in rare flakes having very weak pleochroism) and the total absence of kyanite.

A chemical analysis has been made of a sample of granitic gneiss, representative of a small sialic mass forming one of the peaks that rise from the divide between the Kutiah and Goropha glaciers (Samangi). The weight percentage and the NIGGLI's values are shown in Table 3. A comparison with P. NIGGLI's magmatic types shows that the rock is similar to the aplite granitic types from which it differs in respect of the very low value of *fm*.

TABLE 3

Leucogranitic muscovitic gneiss; *the divide between the Kutiah and Goropha glaciers* (54 PZ-22).

CHEMICAL COMPOSITION

(Analyst: B. Zanettin)

SiO_2	73.28%	MgO	0.18
TiO_2	tr.	CaO	1.16
P_2O_5	0.24	Na_2O	3.84
Al_2O_3	15.21	K_2O	4.74
Fe_2O_3	0.08	H_2O+	0.22
FeO	0.43	H_2O-	0.26
MnO	tr.		
			99.64

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Leucogranitic muscovitic gneiss	416	50.9	3.9	7	38.2	0.45	0.39	1.78
Granite-aplitic type (leucogranitic magmas)	460	47	8	5	40	0.45	0.25	
Yosemite-aplitic type (leucogranitic magmas)	350	45	6	13	36	0.4	0.3	

Basis				*Molecular Norm*	
Q	55.9	Q	= 55.9	Q	26.9
Kp	17.0	L	= 40.5	Or	28.3
Ne	20.9	M	= 1.9	Ab	34.8
Cal	2.6	M′	= 3.6	An	4.3
Sp	0.8	π	= 0.06	Cord	1.5
Hz	1.0	μ	= —	Fe-Cord	1.8
C	1.2	γ	= —	Sil	1.8
Fs	0.1	α	= 45.63	Hm	0.1
Cp	0.5			Cp	0.5

(1) The extinction angles of albite twins in the zone ⊥ (010) is about $8^o — 10^o$; $\gamma' > \omega_q$. The composition of plagioclase than should be 24 — 27% An.

Before finishing this review of the more diffused facies of the migmatitic formation of the Stak zone, I would like to call attention again to the fact that grading from the facies poorer in neosome (augengneisses) to the richer one, the plagioclase, which at first clearly occurs in smaller quantities than potash-feldspar, becomes by degrees more abundant.

PARTICULAR MIGMATITIC TYPES

There occurs in the lower Stak valley rocks formed by alternate clearer and darker bands, similar, at first sight, to the migmatitic banded gneisses frequent in all the zones which I surveyed. They differ from these by virtue of the fact that the dark bands are not formed by pelitic paraschists, but by layers rich in femic components (biotite or amphibole) which grade to the lighter layers.

The observations in the field have unfortunately been very hasty and the samples taken are insufficient for furnishing more detailed knowledge on these rocks; these are again quartzose-feldspathic gneisses, but are very laminated and often correspond to blastomylonites. The most interesting petrographic characteristic is shown by *plagioclases* (30% An) (1) developed as *large crystals* in the fine grained *quartzose-feldspathic matrix*; they are similar to the microperthite porphyroblasts of the common migmatites. The porphyroblasts do not show postcrystalline deformation. The femic minerals in the darker bands are represented by *hornblende* and *epidote*, while biotite is rare; in the lighter bands they are represented by *biotite*, *epidote* and *garnet*, while *hornblende* is very rare (54 PZ-27). These hornblende-rich migmatites grade into a small mass which although aplitic in appearance really corresponds to a *quartzose-feldspathic gneiss* rich in *biotite*, *epidote* and *garnet* (54 PZ-60) similar to the leucocratic layers of these particular types of migmatites.

The rocks now briefly described occur in the proximity of an ultrabasic mass of *hornblendite* (54 PZ-59), which is discordant with the migmatitic gneisses of pelitic type.

(1) $\alpha' \geq \omega_q$; $\varepsilon_q > \gamma' > \omega_q$. The maximum extinction angles of albite twins measured in the zone $\perp$ (010) $= 10^\circ - 15^\circ = 27 - 32\%$ An.

AMPHIBOLITES, CALCIPHYRES AND CALC-SILICATE HORNFELSES INTERBEDDED WITH MIGMATITIC GNEISSES

In the zone around Kulankae (that is in the zone of confluence of the Stak, Goropha and Kutiah valleys), the uniformity of the migmatitic formation is interrupted by the presence of rocks of different types, which are always represented by bands of relatively small thickness concordant with the pelitic paragneisses.

The more common rocks, easily distinguishable in the field by their dark colour, are *garnetiferous amphibolites* sometimes with and sometimes without schistosity. Generally the thinnest bands are clearly foliated; whilst, on the other hand, the inner parts of the largest amphibolic masses, which are many scores of metres thick, have a massive texture.

In other cases foliated and non-foliated bands are interbedded without order. These amphibolites have a very variable grain in different points of the outcrops; but the types with rather coarse grain are predominant. These last are formed almost entirely by green hornblende with which is associated in remarkable quantities a somewhat ferriferous type of *epidote* and sometimes also *garnet*; *quartz* and *plagioclase* 20-45% An (1) are rather rare, while *sphene* is relatively common.

The fine-grained amphibolites generally form thin bands or separate the coarse-grained amphibolites from the other types of rocks; usually they show a greater abundance of garnet and of common hornblende of a green-brown colour.

In some places beds, or more often lengthened bands, can be found inside the amphibolites. These are formed of *crystalline limestones* with patches of amphibolic nodules which grade (at the points where they are crossed by veins of light quartzose or quartzose-feldspathic material) into *calciphyres* and also into *calc-silicate hornfelses*. Among the newer formed minerals the most prevalent is usually *clinozoisite*, associated with *diopside* (2) and also with *biotite*; the *sphene* is always present, while the *plagioclase*, in rather irregular forms, occupies the interstices between the above mentioned minerals.

Other metamorphic rocks derived from partially calcareous sediments grade

(1) Strong variations of composition are found between the individuals of the same rock. The maximum extinction angles of albite twins measured in the zone ⊥ (010), varies from a few grades to 25° (from 22% to 45% An). In one plagioclase crystal I have also measured an angle of 28° = 51% An.

(2) $\gamma \wedge c = 36° - 37°$.

into the pelitic schists of the most common type, but are not always distinguishable from these, in the field, differing only in respect of the presence of *calcite.* Sometimes they are distinguishable by the inclusion of amphibolic nodules.

Finally, it is interesting to note that boulders and numerous pebbles of marble and of calciphyres are found together with amphibolites in the debris on the left flank of the Kutiah valley, and on the left flank of the Stak valley between Kulankae and the deep valley that leads to the village of Rising (Barduma Nala).

TOPOGRAPHIC DISTRIBUTION OF THE VARIOUS MIGMATITIC TYPES

As it has been said, the migmatites occuring in the Stak basin present certain constant characteristics over a considerable area; that means that the variations from one type of migmatite to another occur gradually, so that it is always possible to identify the prevailing rock type in a certain area.

In the lower parts of the left flank *of the Stak valley*, between the lower villages and its outlet in the Indus river, *migmatitic augengneisses*, of characteristic reddish colour are predominant. These same rocks are also found on the opposite side, always in the lower branch of the valley, but at greater heights, i. e., about 4000 m (13,000 ft); lower down, on the valley floor, *migmatitic banded gneisses* are predominant.

At short distance above the outlet in the Indus river there is a long basic mass composed of hornblendites (54-Z 59) discordant relative to the planes of schistosity of the migmatites and, as it seems, associated with the amphibolites of the right side of the Askore valley. Immediately south of this mass there is an area of light rocks having the appearance of *aplitic gneisses* and grading here and there to leucogranitic gneisses. This light mass grades to amphibolic gneisses often interbedded with laminated bands of gneiss of aplitic and pegmatitic appearance. In some places these black and white banded rocks appear densely folded. All these light rocks correspond to those particular migmatitic types already described and indicated as migmatitic quartzose-feldspathic gneisses rich in hornblende, biotite, epidote and garnet (54 PZ-27, 27 a, 60).

On the ridge that separates the lower Stak valley from the Askore valley the gneisses of pelitic origin are succeeded by garnetiferous amphibolites, with which over a short distance they are intimately combined.

The migmatites occurring in this part of the valley also form that part of the southern side of the Indus valley which faces the outlet of the Stak valley.

Exactly at the confluence of the Stak river with the Indus river there is a local anticline (with the axis orientated NE-SW), whose flanks constitute the two opposite sides of the Indus valley, in such a way that the valley is eroded into the crest of the fold.

Further north, in the lower and middle Stak valley, almost to the zone of Kulankae, the trend of the migmatitic gneissic formation is rather uniform on both sides (strike NE-SW, dip 20°-25° SE) and parallel to the axis of the valley.

In the *middle Stak valley*, between the village of Kurchung and the mouth of the Kutiah glacier (which as I saw it in 1954, was only a few hundred metres below the confluence of Kutiah valley with the Stak valley) migmatitic banded gneisses are predominant. These often occur with bands of aplitic type, which are very thin in the more southerly outcrops but which become gradually thicker towards the north.

I have already pointed out the downslope movement of boulders from the higher areas on the left flank (between Barduma Nala and the mouth of the Kutiah glacier). These boulders consist of *amphibole-garnet gneisses*, of rocks very similar to the *hornblendites* occurring in the lower parts of the valley, and also of pure *crystalline limestones*.

The rocks in the *zone of Kulankae* are more varied. Here, besides the usual pelitic migmatites, *paragneisses and micaschists* derived from the metamorphism of original argillaceous sandstones are present, together with *calc-schists*, *calciphyres*, *calc-silicate hornfelses* and *amphibolites* (1).

It is probable that the succession of rocks observed in this zone does not correspond to a normal stratigraphic series, but represents, instead, a repe-

(1) To give an idea of the alternation of the different types of rocks occurring in this zone, I shall describe a series found in an area on the left side of the Stak valley, exactly opposite the outlet of the Kutiah glacier. Moving from south to north, this series included *mica-epidote-garnet gneisses* with calcite, including amphibolic nodules (4 m); *migmatitic banded gneisses* rich in *kyanite* and *garnet* (12 m); *biotite-garnet banded gneisses* interbedded with *pegmatitic gneisses*, in which a thin layer of *pyroxene-garnet hornfels* (15 m) was included; *garnet amphibolites* (20 cm); *migmatitic aplitic gneisses* rich in garnet, interbedded with almost pure *biotite-garnet paragneisses* and *muscovite-biotite-garnet paragneisses* with very impure *aplitic* bands of clear-grey colour (60 m); *epidote amphibolites* (50 m); *garnet amphibolites* (2 m); *muscovite-biotite-garnet paragneisses* (5 m); *garnet amphibolites* (3 m); *mica-garnet paragneisses* with many lenses and nodules of *garnet amphibolites* and *clinozoisite-pyroxene-biotite hornfelses* (80-90 m); these rocks are succeded by *biotite-muscovite-garnet migmatitic gneisses* interbedded with *biotite-kyanite-garnet migmatitic gneisses* which become more abundant and devoid of amphibolitic bands; at first these contain only a few crystals of kyanite, but further crystals of kyanite become more numerous.

tition of a few members, since there is evidence of very close folding (with the axis parallel to the direction of the migmatitic formation), visible in the divide between the Kutiah and Goropha valleys.

The same rocks observed near Kulankae, are also found, with the same distribution, on the left side of the Kutiah valley, together with beds of *marble*; there, however, the metamorphic formation has a general NW-SE trend, (that is nearly at right angles to the trend of the rocks occurring in the middle and lower Stak valley). This trend is continued in the eastern wall of Haramosh, as it can be seen from the slope opposite the Kutiah and Goropha valleys, where interbedding of dark amphibolites and light migmatitic gneisses occurs.

In fact the surfaces of schistosity of the migmatitic gneisses, parallel to the axis of the Stak valley in its lower branches, dip south-east wards with an inclination of 20°-25°. This inclination increases rapidly nearer Kulankae, and becomes almost vertical in places, while at the same time the strike changes to a NW direction on the average, and thus forms a fold with a very inclined axis.

Although I have no samples of this part of the valley, field observations show that on the *right side of the Kutiah valley augen-paragneisses* are predominant in the lower areas and *migmatitic banded gneisses* in the upper areas; together possibly with some *pegmatitic dikes* with well developed crystals of muscovite.

On the *eastern wall of the Haramosh* there are found *migmatitic banded gneisses* with thin bands of paleosome, *folded biotitic gneisses*, *marbles*, *calciphyres* rich in diopside, epidote and actinolite.

On the left side of the *upper Stak valley* between Kulankae and the Stak-la, and especially around Kulankae, one finds *migmatitic banded gneisses* rich in *mica* and *garnet* with small bands of *migmatites* rich in *kyanite* and *garnetiferous amphibolites*. I did not explore the area of the Stak-la, but from the results of samples collected in 1953 by A. DESIO it would seem that the main rocks are gneisses rich in neosome and, above all, aplitic gneisses in which kyanite and garnet are apparent.

Migmatites rich in neosome and *aplitic granitic* and *pegmatitic gneisses* occur also on the right side of the upper Stak valley especially in the *Goropha valley*, where they are variously associated with the *migmatitic banded gneisses*. The transition between different migmatitic types is best seen on the left side of the Goropha valley. In the outcrops nearer to the valley floor one finds the usual dark and light banded gneisses (these last often corresponding to pegmatitic gneisses), while at higher levels the neosome becomes more prevalent than the paleosome (formed by paragneisses very rich in kyanite) and forms the steeper slopes, while the paraschists appear only infrequently as large discontinuous streaks.

Small aplitic and leucogranitic masses poor in neosome also occur in the higher parts of the right side of the Gorophа valley.

These migmatitic rocks are sometimes intersected by discordant dikes; the more common of these correspond to aplitic and pegmatitic veins, and are confined mainly to the eastern part of the zone of Kulankae.

An *amphibolite* and a *pyroxene-amphibole-garnet hornfels*, found in the lower Stak valley, might represent *old femic dikes*, formed before the processes of migmatitization.

CONCLUSIONS

CHEMICAL VALUES

The chemical analysis, made of three characteristic rocks of the migmatitic formation of Stak, can be correlated with the corresponding NIGGLI'S values in the comparative table 4.

Analysis 1 refers to a rock that represents the migmatitic facies containing small quantities of sialic material. It would have been more interesting to have used a "pure" sample, derived only from the metamorphism of an original sediment, but, as I have already said, in all the Stak area I did not find any rocks that are not in some way permeated by neosome.

Analysis 3 refers to a rock practically devoid of coloured elements, forming a mass of considerable extent occurring in the highest part of the divide between the Kutiah and Gorophа glaciers; it is therefore representative of the more sialic rocks that have been observed in the Stak area.

Analysis 2 has been made on a limited sialic band of the more typical arteritic migmatites. The object of this last analysis was to establish a comparison between these sialic bands which are considerably interbedded with the bands of paleosome and the larger sialic masses in which the paleosome can be absent or very scarce over a vast area and which is so permeated by quartz-feldspathic material that it does not enable an easy and sure determination of its original sedimentary nature to be made.

I did not think it useful to make chemical analyses on rocks formed by alternate thin light and dark bands, because, knowing the composition of the paleosome and of the neosome, the result depends only on their quantitative ratio.

TABLE 4
THE STAK MIGMATITES
ANALYSED ROCKS

Locality	Petrographic classification	Chemical classification according to Niggli's « magmatic types »
1. – Left side of the lower Stak valley; 2 km below Kurchung.	Biotite-kyanite-garnet paragneiss with feldspathic lenses and bands (54 PZ-28).	
2. – Left side of the middle Stak valley; 3 km above Kurchung. The light band of a migmatitic banded gneiss.	Quartzose-feldspathic gneiss with biotite, muscovite, garnet and kyanite (54 PZ-29).	Leucogranitic magmas: *engadinite-granitic type.*
3. – The divide between the Kutiah and Gorопha glaciers.	Quartzose-feldspathic gneiss with muscovite and garnet (54 PZ-52).	Leucogranitic magmas: *granite-aplitic* and *yosemite-aplitic* type.

CHEMICAL COMPOSITION

	1 (Analyst: B. Zanettin)	2 (Analyst: B. Zanettin)	3 (Analyst: B. Zanettin)
SiO_2	62.72%	72.52%	73.28%
TiO_2	1.61	tr.	tr.
P_2O_5	0.12	0.28	0.24
Al_2O_3	18.86	14.75	15.21
Fe_2O_3	1.17	0.06	0.08
FeO	6.91	2.08	0.43
MnO	0.07	tr.	tr.
MgO	1.66	0.06	0.18
CaO	0.44	1.35	1.16
Na_2O	1.08	3.62	3.84
K_2O	3.39	4.72	4.74
H_2O+	1.55	0.26	0.22
H_2O-	0.34	0.24	0.26
	99.92	99.94	99.64

NIGGLI'S values

Stak analysed rocks	*si*	*al*	*fm*	*c*	*alk*	*k*	*mg*
1. Paragneiss	262	46.4	38.1	2	13.4	0.67	0.27
2. Migmatitic banded gneiss	391	46.8	10.2	7.8	35.2	0.46	0.47
3. Migmatitic granitic gneiss	416	50.9	3.9	7	38.2	0.45	0.39
NIGGLI'S *magmatic types*							
Leucogranitic magmas:							
Engadinite-granitic type	380	43	13	8	36	0.5	0.25
Granite-aplitic type	460	47	8	5	40	0.45	0.25
Yosemite-aplitic type	350	45	6	13	36	0.4	0.3

The NIGGLI's values resulting from analysis 1 quite understandably do not correspond to any of the known magmatic types, since this is a pelitic paragneiss with "augen" and layers of feldspathic composition.

The high percentage of K_2O of this rock is worth noting. This is attributable in part to the micas, biotite and muscovite, and in part to potash-feldspar which represents the predominant mineral of the augen and of the bands of neosome. Naturally it is not possible to specify exactly how much of this potassium is from the original paraschist and how much was introduced afterwards. The same uncertainty is also present regarding the origin of Na_2O, (the quantity present being less than one third of that of K_2O).

It is interesting to see the definite similarity between the values derived from the analysis of rock samples 2 and 3, which both belong chemically to *leucogranitic magmas*: the first corresponding to the *engadinite-granitic type*, and the second intermediate between the *granite-aplitic* and *yosemite-aplitic types*. The only notable difference between the two rocks concerns the values of FeO (very low values of Fe_2O_3, MnO and MgO cause large variations of *fm* in the NIGGLI's values); such a difference is justified by the fact that in rock with a low percentage of FeO (0,43%) the paleosome minerals have practically disappeared, excepting rare, small garnets and very small relics of biotite, while in rock richer in FeO (2,08%) the biotitic streaks and the garnets of the ancient paraschist are still easily recognizable under the microscope.

In comparison with the paraschist the two rocks of leucogranitic composition have a much larger content of SiO_2 (from 62% to 73%) and of Na_2O (from 1 % to 3,7 %); less evident is the difference of the values of K_2O (from 3.4% to 4.7%).

ANALOGIES WITH OTHER HIMALAYAN FORMATIONS

A migmatitic formation containing identical features to those observed in the Stak basin occupies a large area in the southernmost region, south of the Indus valley and precisely corresponding to the Nanga Parbat group (8125 m; 26.648 ft); this group constitutes the highest elevation of the western part of the Great Himalayan range and lies some tens of kilometres from the Haramosh group (fig. 1).

The Nanga Parbat zone was first observed in detail by D. N. WADIA (1932) and later, in 1934, by P. MISCH (1949). D. N. WADIA, as a result of his experience of Himalayan geology and stratigraphy, has distinguished the different rocks existing here on the basis of chronology. He has set out the relationships between the rocks of sedimentary origin occurring in the south and surrounding the Nanga Parbat group and the more or less gneissose rocks of granitic type that form its central part. The first are represented by a pre-Cambrian formation (Salkhala series) formed essentially of dark, sometimes metamorphic argillaceous rocks, interbedded with limestones and greenstones. The second type is thought to consist of ancient granites here called "central gneisses" to indicate their connection with the gneisses forming the axial part of the Himalayan range.

P. MISCH, on the other hand, in describing briefly the geological conditions of the region, presents evidence of the geological and petrological characteristics of the rocks observed, and treats the petrogenesis of the migmatitic formation in a very interesting way.

The exceptional interest in this area, shown by the works of the two Authors mentioned above, is represented by the fact that in different parts of it the *argillaceous rocks of the Salkhala series have undergone different degrees of regional metamorphism* (from the slates to the katazonal facies). *At the same time these rocks of sedimentary origin and the quartzose-feldspathic material of granitic-aplitic or pegmatitic composition are associated in all possible quantitative ratios.*

According to P. MISCH the black carbonaceous slates that occur south-east of Nanga Parbat have undergone a progressive metamorphism towards north and west, that is both along and across the strike, changing gradually to *phyllitic slates* in the upper part of the epizone (sericite, quartz, chlorite and sometimes albite), to *phyllites* in the lower part of the epizone (where small porphyroblasts of manganese-rich garnet appear), to *micaschists* and *paragneisses* in the upper part of the mesozone (biotite, muscovite, quartz, oligoclase and garnet). In the *paragneisses* of the lower mesozone the kyanite and a small quantity of potash-feldspar appear; whilst in the rocks of the katazone sillimanite and a considerable amount of potash-feldspar are present.

The migmatization begins contemporaneously with the appearance of the kyanite, in the lower mesozone. At first large porphyroblasts of potash-feldspar occur which, when combined in fairly well developed lenses, form *migmatitic augengneisses.* The progress of the metamorphism is accompanied by a more intense migmatization which causes the formation of concordant layers (*migmatitic banded gneisses*) which become gradually thicker until the sialic material is much more abundant than the paleosome and eventually forms masses of *migmatitic gneissic granites* of batholithic dimensions in the inner areas of the Nanga Parbat group.

According to P. Misch, therefore, the process of migmatization begins in the lower mesozone and increases with the advance of metamorphism.

In the same way the impure limestones have undergone progressive metamorphism and pure limestones have become marbles.

The calcareous sediments differ from the rocks of argillaceous origin in that they have not undergone the processes of migmatization and so very long thin regular bands of white marble appear enclosed in the very extensive masses of granitic gneisses.

The slates, the epizonal rocks, and also the katazonal ones (sillimanite paragneisses) are missing in the basin of Stak, but perfect similarity of the kyanite-garnet paragneisses studied by me to those existing in the area of Nanga Parbat is sufficient reason to consider the paraschists of Stak as the metamorphic equivalent of the formation that, according to D. N. Wadia, represents the Salkhala series.

The close analogies between the rocks of Stak and those of Nanga Parbat are also shown by the fact that both the migmatitic formations have a general trend NE-SW (dipping towards the SE in the zone of Stak, and towards the NW in the zone of Nanga Parbat). This according to D. N. Wadia (1932) is the prevalent tectonic characteristic of all the Nanga Parbat area.

On the basis of this observation one can deduce that the migmatites which form the Haramosh and Nanga Parbat groups are not only similar, but represent the same formation. Very probably, they are directly united by a belt that occupies the zone south of the Indus valley that has not yet been surveyed.

As I have already pointed out near Kulankae the general trend of the migmatitic formation changes rapidly, the strike assuming a NW-SE direction, nearly at right angles to the one shown by the same formation for a distance of about one hundred kilometres in the southern area. I briefly report that the formations occurring east of the basin of Stak and also east of the Nanga Parbat group (D. N. Wadia, 1932) have a general NW-SE strike; according to D. N. Wadia this is the dominant strike of the Himalaya south of Astor (in the homonymous valley, east of Nanga Parbat).

PETROGENESIS

The relationships observed in the field between paleosome and neosome and some of the petrographic characteristics disclosed under the microscope seem to indicate that the Stak migmatites have been formed through the chemical reaction between pre-existing paraschists and materials introduced into them (metasomatic process) rather than by simple injections "lit par lit" of magma of granitic or aplitic composition.

P. MISCH (1949) has discussed at length the genetic problem of the migmatites occurring in the Nanga Parbat area, affirming with convincing arguments their metasomatic origin. Because of the similarity between the geological and petrographic characteristics shown by both the migmatites of Nanga Parbat and of Stak, the conclusions formulated by P. MISCH about the processes that caused the formation of the Nanga Parbat rocks may be considered valid, in general terms, for the rocks observed by me.

In one of my preceding papers (B. ZANETTIN, 1957) concerning solely with petrographic characteristics, I accepted the hypothesis put forward by P. MISCH according to which these Himalayan migmatites were formed by a metasomatic synkinematic (synorogenic) process of granitization. I accepted this either as a result of the observations made by MISCH (and to a large extent confirmed by me) or as a result of original considerations.

For the purpose of this study the discussion of the genetic problem will be limited to its essential terms; the conclusions expounded by P. MISCH will be printed in small type and will be followed by the exposition of those arguments which, in my view, support his genetic hypothesis.

To support "a metamorphic-metasomatic rather than an intrusive origin" of the migmatitic gneisses, P. MISCH (1949, p. 235-236) puts forward the following arguments:

"Variability of composition, grain size and other textural features; uneven nature of texture; frequent presence of porphyroblastic features; crystalloblastic texture (...) Apart from the character of the gneiss itself, there are *other even stronger arguments in favour of an origin by metasomatic granitization.*

The first is the presence of *intercalations of undoubted metamorphic sediments* and some basic rocks which, although quantitatively subordinate, occur throughout the wide area of granitic gneiss. *These intercalations are structurally conformable with the granitic gneiss.* Most of them are thin, and many of them can be followed for long distances. It is difficult to visualize that mechanical intrusion of magma could have spared such septa and, even if it did, could have left them structurally intact without thoroughly disturbing and disrupting them. If, on the other hand, these intercalations are interpreted as relict bands which have escaped metasomatic granitization, their presence and their mode of occurrence are readily understood.

Many of these intercalations consist of katazonal fine-grained paragneiss whose contacts with the granitic gneiss are usually gradational. Some layers within such paragneiss intercalations may be partially granitized, having been transformed into feldspar-porphyroblast-schist and porphyroblastic augengneiss. Often paragneiss and granitic gneiss alternate in parallel layers. All these features indicate granitic replacement rather than intrusion.

Of particular interest are the *thin marble layers* with their associated lime-silicate-granulite bands, which form regular conformable intercalations in the gneiss often traceable for long distances. None of the marble layers observed exceed a thickness of 100 feet and most of them are much thinner. No intrusion could have left these bands structurally intact; moreover, it is difficult to comprehend how the marbles could have escaped fusion if the temperature had been high enough to keep silicate compounds in a molten state at the existing pressure for a considerable time in the large magmatic masses surrounding the marbles. There is more marble relative to metamorphic argillite in the interior of the gneiss massif than in the area of non-granitized Salkhala phyllite and of schist and paragneiss derived from it. The absolute proportion of marble, on the other hand, is nearly of the same order in the interior of the massif as in the non-granitized areas. This proves that most of the argillites which greatly predominate in the original sedimentary section, became transformed into granitic gneiss whereas most, if not all, of the marbles escaped granitization — a truly metasomatic process, and one of differential character."

Following the petrographic descriptions reported by me in the preceding chapter, one of the more evident characteristics of the migmatites of Stak is the porphyroblastic development often assumed by the feldspars; the growth of these porphyroblasts has evidently occurred at the expense of the pre-existing minerals enclosed in them, as can be seen in the photographs reproduced in Plate 4, figs. 1 and 2.

Other features supporting a metasomatic origin of the Stak migmatites are:

(1) *The presence of kyanite in the sialic bands* (Plate 3, fig. 2). P. MISCH has already called attention to this fact concluding that since "pure alluminium-silicate would hardly crystallize in a rock so rich in potash" the kyanite must represent an unstable relic. That the kyanite usually represents a relic also seems to be proved by two facts that we can often observe in the Stak rocks; firstly and directly some mica-kyanite-garnet-rich bands of the paleosome pass laterally to feldspathic bands including only kyanite and garnet (the micas should be progressively transformed into feldspar by reaction with the introduced materials); secondly and indirectly *the sialic bands interbedded with schists devoid of kyanite (mica-garnet paragneisses) are themselves devoid of kyanite.*

(2) *The persistence, in the sialic bands, of some textural characteristics of the paleosome.* Under the microscope the lighter portions of the migmatitic formations are seen to be formed by an alternation of very elongated layers

of pure quartz, and by bands parallel to those in which grains of quartz and sodic plagioclases are associated with the presence of a great quantity of potash-feldspar, either in porphyroblasts or in smaller crystals (Plate 3, figs. 3 and 4). Since fine-grained quartz layers in the paleosome alternate with more or less micaceous beds including a variable quantity of quartz grains and plagioclase, it is not difficult to realize that the quartz bands of the paleosome correspond to the more crystalline quartz bands of the neosome (*), and the micaceous bands of the paleosome to the feldspar bands of the neosome.

To demonstrate that the granitization of the pelitic schists is synkinematic P. Misch (1949, pag. 692-693) writes:

"The evidence of synkinematic crystallization in higher grade metamorphic rocks is also evidence of a synkinematic metasomatism in associated granitized rocks. In fact, in non-granitized and granitized rocks occurring together, crystallization differs only insofar as in the latter, in addition to substances of the original rocks, introduced material has participated. Therefore, both groups of rocks show essentially similar structural features indicative of synkinematic origin. The main criteria observed in the field are: well developed schistosity and a general sharp parallelism of such elements as bands, stringers of porphyroblasts, etc., and an absence of cross-cutting relationships features which are typically developed at Nanga Parbat as well as in many other areas.

Microscopic criteria are numerous. Many of them have been described for regionally metamorphosed rocks in B. Sander's fundamental treatise on metamorphic fabrics (1930, pp. 262-275). Similar features are often found in synkinematically granitized rocks like those of Nanga Parbat. General criteria for synkinematic crystallization include: "snow ball garnets" and other porphyroblasts rotated during growth; the occurrence, in the same thin section, of folds composed of deformed minerals such as micas, and of other folds consisting of undeformed micas in a polygonal arrangement ("polygonal arcs"); the presence of polygonally arranged, undeformed, and folded micas in different parts of the same microscopic fold; the superposition of slight folding in a polygonal arc, both mechanical bending and polygonal arrangement representing the same pattern of deformation; fracturing and subsequent healing of crystals which may result in elongation parallel to the schistosity; generally speaking, the frequent occurrence of several overlapping successive submaxima both of deformation and crystallization, which can be individually dated by certain mineral species (one species sometimes having more than one maximum of crystallization); thus detailed chronological analysis is possible, and, as a whole, one continuous major process consisting both of deformation and crystallization is indicated. Furthermore, the common metamorphic structure termed "crystallization foliation" (well-developed schistosity without mechanical disturbance of crystal lattices) is rarely due to entirely static mimetic crystallization; under static conditions usually some transversely oriented crystals

(*) Since the sialic bands are formed by reaction between the material of paleosome and the material introduced therein it would be more exact to call these bands *metasome* after the meaning given to it by H. K. Scheumann.

develop, and if mimetic granitization is added, invariably cross-cutting contacts also form. Typical crystallization foliation may rather be considered as a result of crystallization which was mainly synkinematic and was able to heal lattice disturbances caused by contemporaneous deformation, and which usually lasted somewhat longer than deformation so that any remaining lattice disturbances were eliminated.

With regard to the observation that the perfect conformity of paleosome and neosome bands indicates the synkinematic nature of these migmatites I can add that the long thin micaceous layers which represent the direct continuation of the dark bands into the light bands have the same meaning. A process of static granitization would not have so frequently preserved portions of similar shaped paleosome as to become the rule, but each band would have been reduced to isolated fragments on the same plane. This occurs in our rocks only when the layers become extremely thin in the phase that immediately precedes their total disappearance.

SUMMARY OF THE GENETIC PROCESSES

The rocks occurring in the Stak basin correspond to migmatites in which the *paleosome* is represented by paragneisses rich in *biotite*, *kyanite* and *garnet*, and the *neosome* by *gneisses* of *granitic-aplitic composition usually including relics of kyanite and garnet.* One of the most evident characteristics of this mixed formation is the almost perfect parallelism existing between the dark bands of paleosome and the light bands of neosome. In the lower branch of the Stak valley the series poor in neosome prevails, but the neosome becomes gradually more abundant in the northern branch. The mineralogical composition of the paleosome remains constant in all the migmatitic series.

On the basis of the geological and petrographic characteristics observed and discussed in the preceding chapters it is possible to present a synthetic picture of the probable processes which have acted successively on the argillaceous pre-Cambrian rocks (Salkhala series) occurring in the Stak area and which have determined the formation of the actual migmatites.

The original argillaceous rocks, subjected to a gradually increasing metamorphism, would have given place at first to schists of the epizone and upper mesozone (micaschists and muscovite-biotite paragneisses with or without garnet), then, with the progressive increase of temperature caused by the advance of the granitizing solutions, would have formed the facies containing kyanite and garnet, and often some potash-feldspar (all these minerals would have formed at the expense of muscovite and biotite). Temperatures high enough to permit the appearance of sillimanite have never been reached. On the other hand, rocks rich in sillimanite are very common in the Nanga Parbat area.

Contemporaneously with the formation of the kyanite occur the first feldspars of metasomatic origin, produced by the reaction between the micaceous minerals of the paraschists and the introduced materials (mainly alkali and silica). According to the intensity of the transformations caused by the introduced substances either isolated porphyroblasts (*migmatitic augengneisses*) can form in the paraschists, or feldspathic bands of different thicknesses (*migmatitic banded gneisses*) in which remain relics of the minerals that have either not taken part in the metasomatic reactions or which are more able than the micas to withstand the processes of the alkaline substances (kyanite and garnet), or, finally, small gneissic masses of granitic aspect (*migmatitic granitic gneisses*) containing bands of paraschists.

The nature of the feldspars of metasomatic origin also changes with the variation in intensity of this process of granitization. In the lower branch of the Stak valley, where migmatitic types poor in neosome occur, the potash-feldspar is by far the most abundant neoformed mineral. In the northern zones, however, where the neosome is much more abundant, a remarkable quantity of calc-sodic plagioclase (oligoclase) occurs; in rocks of pegmatitic aspect tourmaline is present together with the potash-feldspar.

Since these metasomatic transformations have occurred under the action of shearing stresses, the metacrystals have assumed a definite disposition in respect to the surfaces of schistosity thereby giving the sialic rocks an orientated texture, which is accentuated by the presence of bands of mica remnants.

II

THE ASKORE - TWAR ZONE

This zone extends eastwards of the Stak valley. To the west it embraces all the territory which is bounded by the watershed between the Stak valley and the Askore valley; to the north it is bounded by the irregular crest dividing the valley of the Indus from the upper Turmik valley, to the east by a small, steep valley that descends from a height of about 4000 m (13,000 ft) to the Indus river a little east of Mulakor; and to the south by the Indus river, besides which runs the Skardu-Gilgit caravan-trail.

The western limit of this region almost coincides with the boundary between the migmatitic Stak formation and the Askore amphibolites.

The northern and southern limits are however purely topographical because, from direct observation, the rocks occurring in this area extend still further to the north. South of the Indus valley the only observations made were telescopic.

At the eastern limit the dioritic-noritic rocks that characterize the Askore-Twar zone are separated by a narrow band of schists from the essentially sialic rocks (plagioclase gneisses) which outcrop on the right side of the Indus river, between the village of Skoyo and the mouth of Turmik valley.

The *Askore valley* is long, difficult, and very narrow, especially in its lower reaches. Because of the instability of patches of morainic material on the very steep valley sides and of the state of decay of the rocks "in situ", it is not possible to penetrate up the valley floor and the only way of access is along the crests dividing the valley from those adjoining. It is because of this, together with the absence of villages, and the uniformity of the geological formations intersected by the valley along the strike, that only a limited number of excursions have been made by me in this area.

In addition to the area at the mouth of the Askore valley, I surveyed a good part of the right side of the valley up to a point not very far from the confluence of the two (or three) principal branches. No direct observations were possible on the left side, nor in the more northerly part of this basin where

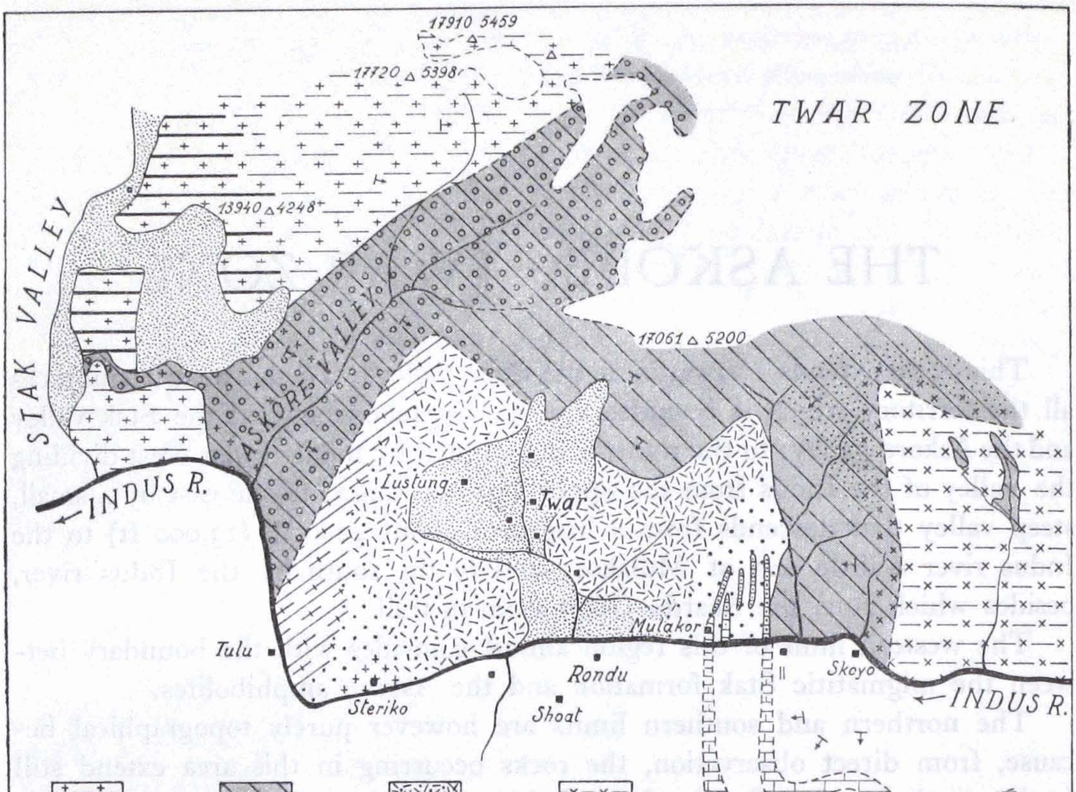

Fig. 5 - Geological sketch-map of the Askore and Twar basins.

1, 1 a, 1 b - Migmatites with pre-Cambrian paleosome:

1 - Migmatitic augengneisses;
1 a - Migmatitic banded gneisses;
1 b - Migmatitic granitic and pegmatitic gneisses.

2, 2 a, 2 b, 2 c - Cretaceous basic schists:

2 - Amphibolites, epidote amphibolites, biotite-amphibole gneisses etc.;
2 a - Garnetiferous amphibolites;
2 b - Basic schists with mica or amphibole porphyroblasts;
2 c - Agmatites with elements of basic schists cemented by plagioclase gneisses.

3, 3 a, 3 b, 3 c - Rocks of the Twar basic mass:

3 - Hypersthene diorites and norites;
3 a - Quartz diorites and pyroxene-bearing biotite-amphibole granodiorites;
3 b - Gabbrodiorites and amphibole gabbros;
3 c - Metadiorites, metanorites (metamorphites of the types 3, 3 a, 3 b).

4 - Plagioclase gneisses.

5 - Limestones and dolomites; 5 a - Marbles, calciphyres and calc-hornfelses.

6 - Moraine, alluvium and debris.

the higher peaks within the area bounded by the Indus, Stak and Turmik valleys are found.

The remaining part of the area under discussion is indicated as "*Twar zone*". This zone does not have a definite geographical individuality, but it is so named because it extends around the large valley at the bottom of which lie the village of Twar and other smaller villages (opposite the plateau of Rondu). This large valley, broad and short, formed by the erosion of a thick moraine, changes rapidly towards the north into a steep valley that notches the ridge separating the Indus valley from the Turmik valley. The lower part of the Twar valley is also fed by a very narrow canyon, bringing water from the east, and cut into massive rocks. This canyon widens at a height of about 2700 m (9.000 ft) into a shallower valley.

In general this area can be surveyed without much difficulty, except the northern ridge which, at the time of my visit, was still covered by a great deal of snow at heights above 4500 m (15,000 ft).

The geological characteristic of greater interest in the Askore-Twar zone is the presence of a basic mass bounded by amphibole, amphibole-biotite, and biotite schists intercalated with limestones and calc-schists.

GEOLOGICAL CONDITIONS AND PETROGRAPHIC FEATURES

THE COUNTRY ROCKS

The rocks surrounding the basic mass occupy less than one third, though the most northerly and highest part, of the Askore-Twar area, and form only a thin band towards the east (Skoyo). The rocks are schistose and most commonly represented by *fine-grained amphibolites*, often with needle-like amphiboles, in very thin bands, easily recognizable in the field. The principal mineralogical components of these amphibolites are *plagioclase* (20-30% An) (1), and *green hornblende*, whilst *quartz* is always scarce and distributed as small grains. *Epidote* accompanies the amphibole in very variable quantities and

(1) The extinction angles measured in the zone ⊥ (010) of the albite twins and on different samples are as follow ($\gamma' > \omega_q$, rarely $\gamma' = \omega_q$):

5°-7° = 23-25% An;
4°-5° = 23% An;
7°-10° = 25-27% An;
9°-12° = 27-29% An;
13°-18° = 30-35% An.

biotite, sometimes completely absent, can in some cases assume such abundance that the rocks become amphibole-biotite gneisses (54 PZ-18, 67, 68, 70). Sphene is nearly always a common subsidiary. The nicer variations in these fine-grained amphibolites concern the quantitative ratio between the feldspars and amphiboles. This ratio is also easily determined by macroscopic observation on the basis of the darkness of the rock. Calcite may also be occasionally present though it is not known whether it is primary or secondary.

TABLE 5

Amphibolite; *at a height of about* 3.500 *m* (11,500 ft) *above Mulakor* (54 PZ-70).

CHEMICAL COMPOSITION

(Analyst: B. Zanettin)

SiO_2	49.83%	MgO	8.32
TiO_2	0.53	CaO	9.61
P_2O_5	0.24	Na_2O	3.35
Al_2O_3	17.10	K_2O	0.35
Fe_2O_3	2.11	H_2O+	1.60
FeO	6.54	H_2O-	0.06
MnO	0.25		
			99.89

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Amphibolite	114.6	23.2	45.3	23.7	7.8	0.07	0.63	0.52
Normal gabbroic type	108	21	51	22	6	0.2	0.5	
c-gabbroic type	100	25	46	25	4	0.1	0.7	
Normal gabbrodioritic type	130	23	44	22.5	10.5	0.2	0.5	

Basis				*Molecular Norm*	
Q	29.2	Q	= 29.2	Or	2.0
Kp	1.2	L	= 37.8	Ab	30.2
Ne	18.1	M	= 32.1	An	30.8
Cal	18.5	M′	= 33.0	Wo	6.3
Cs	4.7	π	= 0.49	En	14.0
Fs	2.2	μ	= 0.54	Fo	6.8
Fo	17.3	γ	= 0.15	Fa	6.8
Fa	7.9	α	= 0.37	Mt	2.2
Ru	0.4			Ru	0.4
Cp	0.5			Cp	0.5

A chemical analysis was made on one of these fine-grained amphibolites (54 PZ-70). The weight percentages and the corresponding petrochemical data are given in Table 5. NIGGLI'S values show that this rock can belong to the group of the *gabbroic magmas* and exhibits similarities with both the *normal gabbroic* and the *c-gabbroic* types. A certain similarity with the *normal gabbrodioritic* type of the group of *gabbrodioritic magmas* is also worth noting.

The fine-grained amphibolites pass either gradually or rapidly into the *amphibole-biotite* or *biotite-amphibole* or *biotite gneisses.* It can be said that the difference between these gneisses is due to the quantitative ratio between the femic minerals, the plagioclase remaining nearly constant in composition and, within certain limits, in quantity.

Biotite schists rich in anthophyllite with a similar appearance to common micaschists are rarer, and are thinly interbedded with greenish bands of *actinolite schists* (54 PZ-71); they are rocks almost, or totally lacking in feldspars, and in which quartz occurs as elongated lenses or as grains scattered in the micaceous bands.

To this series of metamorphic rocks belong also carbonatic rocks such as *calc-schists and marbles,* which form some elongated bands among the dark amphibolite schists.

The most amphibolic rocks, like the *fine-grained amphibolites* and those intermediate to the *biotite-amphibole gneisses* occur in the schistose belt that separates the basic Twar mass from the gneisses rich in feldspathic porphyroblasts that occur east of Skoyo. The thin interbedding of layers more or less rich in feldspar, amphibole, biotite or epidote gives them a characteristic aspect, the beds being of different colours. It must be remembered that the quantity of amphibole increases in those rocks nearest to the calcareous interbedding.

The rocks of this belt have a north-south strike, with a dip to west up to a height of about 3000 m (10,000 ft), and they then assume a north-west strike with a dip to south-west,, enveloping the basic mass and forming the terrain between this mass and the ridge that separates this zone from the upper Turmik valley.

At the north-east boundary of the zone, at heights corresponding to the upper part of the steep valley that leads towards the east of Mulakor, these prevailingly dark rocks become interbedded with *actinolite schists, biotite schists* rich in anthophyllite, and light *paragneisses,* which become increasingly frequent eastwards towards the Skoyo-Turmik zone.

The beds of *marble* have been located "in situ" only in the vicinity of Mulakor, at the bottom of the Indus valley, where they are in direct contact with the massive textured basic rocks by which they have been partially transformed to *calciphyres* and to *calc-silicate hornfelses* (1). The original continuity of these beds has been broken by processes of injection and assimilation by the basic mass, but for some hundreds of metres their trend can still be followed.

At greater heights, between 3000 and 4000 metres (10,000-13,000 ft), although I have followed the schistose formation across the strike, it was not possible to locate these calcareous beds, which are, however, perfectly clear on the opposite, left side of this valley. There, after having risen for several hundreds of metres keeping a constant trend (strike north-south, with a subvertical dip to west) the strike changes rapidly (about 90°) to an east-west direction, with a dip to south; they then continue crossing the valley of the Indus again about twenty kilometres further upstream, immediately south of the village of Tungas.

Other evidence of the existence of calcareous rocks in this zone is given by the *epidote-pyroxene calciphyres* occasionally present in the alluvium deposited by the torrent that flows into the Twar valley from the north (54 PZ-66).

THE DIORITIC-NORITIC MASS

The basic mass occupies the greater part of the Askore-Twar zone and is limited to the west by the migmatitic Stak formation, to the north by the amphibolites and fine-grained amphibole-biotite gneisses, with which it comes into contact at heights between 3000 and 4000 metres (10,000-13,000 ft), to the east by the marbles interbedded with amphibolitic gneisses, and towards the south it continues almost certainly on the left side of the Indus river. In fact, therefore, in this zone the mass outcrops from the floor of the Indus valley up to heights of from 3000 to 4000 metres (10,000-13,000 ft).

The rocks that form this mass show a remarkable variability of chemical composition, of mineralogical composition, of grain, and of texture. It can be said nevertheless that, except for the rocks of the more western outcrops, strongly altered by metamorphism, it is always possible to meet, both in the field and in microscopical observations, the petrographic characteristics common to the different types of rocks forming the basic Twar mass.

The more typical and more diffused outcrops have the aspect of microdiorites, sometimes also of microtonalites, and macroscopically do not show orientation of the minerals, though this is nearly always seen under the microscope. The essential mineralogical components are plagioclase and pyro-

(1) The most common rocks are actinolite ($\gamma \wedge c = 12^{0}$-15^{0}) calciphyres rich in hedenbergitic diopside and epidote.

xene, either orthorhombic or monoclinic (Plate 5, figs. 1 and 2). *The plagioclases* occur as crystals of very constant composition (about 40-50% An) (1) which remains constant throughout the mass. In general the plagioclases are present as elongated, suborientated, crystals. The frequent parallel texture of the rock is emphasized, under crossed nicols, by the sub-parallel arrangement of the rather broad polysynthetic twinning lamellae of uniform thickness. In such cases, the aspect of these rocks reminds us of that shown by some anorthosites having parallel texture (Plate 5, fig. 4).

In some specimens very thin needle-like crystals with a definite orientation and of unknown composition penetrate the plagioclases. Microperthite is present in patches, without form, and encloses small plagioclases. It is very scarce or even absent in the more femic facies (2). The same is also true of *quartz*.

Orthorhombic pyroxene, of the *hypersthene* variety (3), and *monoclinic pyroxene*, corresponding to a *hedenbergitic augite* (4), form the more abundant femic minerals and often develop around each other. Hypersthene generally forms the central portions, and augite the outer parts (Plate 5, fig. 2). The reddish lamellar inclusions, regularly distributed, are found in both the pyroxenes and represent another microscopic characteristic feature of these rocks (Plate 6, fig. 2).

The association of the two pyroxenes is often followed towards the outside by green *hornblende* or also by hornblende and *biotite* which coat the pyroxenes (Plate 6, fig. 1). It must be remembered that while the pyroxenes always show a remarkable idiomorphism, the amphibole and the biotite sometimes can be poikiloblastic, especially in the extreme rim (Plate 6, fig. 4).

The chemical analysis of samples (54 PZ-21), the corresponding NIGGLI's values and the molecular norm are given in Table 6. Clearly the rock corresponds perfectly to the *normal dioritic type* of the *dioritic magmas*.

The rocks that best correspond to the type described are particularly common west of Twar and can be said to form more or less a semicircle bordering the large morainic deposits that cover the wide valley of Twar and the plain of Lustung.

(1) The measurements done on the albite-Carlsbad twins give the following composition: 40% An; 42% An; 43% An; 46% An; 48% An; 49% An; 50% An.

Only in one sample (54 PZ-64) more calcic terms have been found: 60% and 85% An (albite-Carlsbad twins). In another rock sample the marginal portion of some plagioclases show a very low percentage of An: 30-34-35% An (albite-Carlsbad twins).

(2) Rare K-Feldspar individuals show very small $2V\alpha$ angle: 10°-20°.

(3) Pleochroism: α and β = pink; γ = greenish - grey.

(4) Weak pleochroic: it shows light greenish colour. $\gamma \wedge c = 42^\circ$-$45^\circ$; $2V\gamma = 56^\circ$-60° up to 66°.

TABLE 6

Hypersthene diorite; *between Twar and Steriko* (54 PZ-21)

CHEMICAL COMPOSITION

(Analyst: E. Callegari)

SiO_2	53.52%	MgO	4.30
TiO_2	0.96	CaO	7.99
P_2O_5	0.38	Na_2O	3.66
Al_2O_3	18.40	K_2O	1.69
Fe_2O_3	1.69	H_2O+	0.77
FeO	6.05	H_2O-	0.06
MnO	0.15		
			99.62

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Hypersthene diorite	145.1	29.4	34.9	23.2	12.5	0.23	0.50	0.66
Normal dioritic type	155	30	35	21	14	0.3	0.5	

Basis				*Molecular Norm*	
Q	34.5	Q	= 34.5	Q	0.5
Kp	6.0	L	= 43.3	Or	10.0
Ne	19.9	M	= 20.7	Ab	33.2
Cal	17.4	M′	= 22.2	An	29.0
Cs	2.6	π	= 0.40	Wo	3.5
Fs	1.8	μ	= 0.43	En	12.0
Fo	9.0	γ	= 0.13	Hy	8.5
Fa	7.3	α	= 0.76	Mt	1.8
Ru	0.7			Ru	0.7
Cp	0.8			Cp	0.8

In general, apart from the usual variations of grain, the *hypersthene diorites* present a certain constancy of characteristics, both microscopic and macroscopic. Exceptionally some rounded patches show a greater idiomorphism of the plagioclases, which occur as crystals of remarkably greater dimension than those of the common rocks (54 PZ-64) and as small masses a few metres in diameter, formed by a rock of which I did not take a sample, but similar in appearance to the hornblendites. As it will soon be shown in greater detail, towards the west the rocks of this type become gradually more schistose until they give way to amphibolitic gneisses. A facies with so little evidence of schistosity, as to be hardly distinguishable from the facies of the hypersthene diorites, even though it reveals under the microscope the typical texture of metamorphic rocks, occurs near Steriko, at heights a little above the bottom of the valley. A sample (54 PZ-62) suffices to show how a metamorphic action has caused not only textural transformations, but also mineralogical transformations. Here it has caused the total disappearance of the pyroxene and a relative increase of poikiloblasts of hornblende (Plate 6, fig. 1), while the plagioclase maintains in its composition and aspect a similarity to that of the hypersthene diorites and norites.

A chemical analysis has been made on this sample (Table 7). The NIGGLI'S

TABLE 7

Diorite; *near Steriko* (54 PZ-62).

CHEMICAL COMPOSITION

(Analyst: E. Callegari)

SiO_2	51.14%	MgO	4.48
TiO_2	0.87	CaO	8.32
P_2O_5	0.32	Na_2O	3.31
Al_2O_3	19.00	K_2O	2.36
Fe_2O_3	2.07	H_2O+	1.46
FeO	6.12	H_2O-	0.04
MnO	0.19		
			99.68

NIGGLI'S values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Steriko diorite	133.4	29.2	35.3	23.2	12.3	0.32	0.49	0.66
Normal dioritic type	155	30	35	21	14	0.3	0.5	
Orbitic type (dioritic magmas)	135	27	42	21.5	9.5	0.25	0.5	

Basis			*Molecular Norm*	
Q	31.9	Q = 31.9	Or	14.2
Kp	8.5	L = 44.9	Ab	30.2
Ne	18.1	M = 22.0	An	30.5
Cal	18.3	M' = 23.2	Wo	3.9
Cs	2.9	π = 0.41	En	8.3
Fs	2.2	μ = 0.43	Fo	3.1
Fo	9.4	γ = 0.13	Fa	6.4
Fa	7.5	α = 0.25	Mt	2.2
Ru	0.6		Ru	0.6
Cp	0.6		Cp	0.6

values for this rock also indicate a composition similar to that of the *normal dioritic* type of the *dioritic magmas*.

East of the Twar valley near a deep and very narrow canyon with a north-south direction, there are clearer rocks, considerably more sialic than those mentioned above, corresponding to ***hornblende-biotite-pyroxene quartz diorites and tonalites*** (54 PZ-65) but still having a strict analogy with the noritic rocks that occur to the west. Such analogies are shown by the ***plagioclases***, perfectly similar in composition and appearance to those of the basic rocks already described, and by the ***pyroxene-amphibole associations*** in which the augite forms the core. On the contrary the more marked differences are found in the extreme poikiloblastesis of the green ***hornblende*** (Plate 7, figs. 1 and 2), by the total absence of orthorhombic pyroxene and by the relative abundance of potash-feldspar, and even more of ***microperthite*** that, in large patches, encloses pieces of ***quartz*** and ***plagioclases*** (Plate 6, fig. 3). A chemical analysis has also been made on this more sialic facies (Table 8) which shows that our rock corresponds well to the ***normal quartz dioritic type*** of the ***quartz dioritic magmas***.

TABLE 8

Biotite-amphibole-pyroxene quartz diorite; *near Twar* (54 PZ-65).

CHEMICAL COMPOSITION
(Analyst: E. Callegari)

SiO_2	58.49%	MgO	3.30
TiO_2	0.67	CaO	6.20
P_2O_5	0.25	Na_2O	3.49
Al_2O_3	17.51	K_2O	2.51
Fe_2O_3	1.92	H_2O+	0.66
FeO	4.36	H_2O-	0.06
MnO	0.19		
			99.61

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Twar quartzdiorite	182.1	32.1	31.7	20.7	15.5	0.32	0.48	0.65
Normal quartzdioritic type	225	32	31	19	18	0.25	0.45	

Basis				*Molecular Norm*	
Q	40.3	Q	= 40.3	Q	8.3
Kp	9.0	L	= 43.0	Or	15.0
Ne	19.0	M	= 15.7	Ab	31.7
Cal	15.0	M′	= 16.7	An	25.0
Cs	1.4	π	= 0.35	Wo	1.9
Fs	2.0	μ	= 0.44	En	9.2
Fo	6.9	γ	= 0.09	Hy	5.9
Fa	5.4	α	= 2.09	Mt	2.0
Ru	0.5			Ru	0.5
Cp	0.5			Cp	0.5

These quartz diorites and tonalites form an irregular and softened belt in the north-eastern portion of the Twar mass and pass, towards the contact, to more sialic rocks of *granitic* appearance which form the extreme border of the mass towards north, while towards the lower part they pass gradually into *diorite*, *gabbrodiorite* and *amphibolic gabbros* which in close proximity to the *limestones* assume a very coarse and sometimes exceptional grain.

It is worth describing briefly the relations between these gabbroic rocks and the surrounding limestones as shown by the observations made in the outcrops crossed by the Skardu-Gilgit caravan-trail close to the village of Mulakor, on the floor of the Indus valley. From east to west, that is to say from the surrounding rocks towards the basic mass, the fine-grained amphibolite gneisses are succeeded by some marbles enclosing dark patches formed by amphibolic material with well developed crystals. These dark inclusions become more and more frequent so that, after 10-15 metres, the regular trend of the calcareous beds can be recognised only for a short distance, while inclusions some tens of metres long assume the aspect of a gigantic breccia, with large gabbroic nodules with well developed amphibole (54 PZ-19) bound by a matrix of marbles. Further on the dominant rocks are gabbros, with large amphiboles (up to 10 cm) mixed with bands of *calciphyres with much lime-silicate*; eventually the basic rock assumes a more common appearance with medium or medium-fine grain (54 PZ-20) yet still including some patches of strongly metamorphic calcareous rock and finally passes, very slowly, into the dioritic and tonalitic rocks already described.

The more obvious characteristic in this particular facies developed near the contact with the limestones is the variability in the quantitative ratio between the sialic and the femic minerals. Under the microscope other more interesting features are seen: the cloudiness of the *plagioclase* (labradoritic andesine 40-50% An) due to the inclusion of numerous small flakes of sericite; the presence of *epidote* along the boundaries between the *plagioclase* and *amphibole*; the abundance of *calcite* and the frequency of *sphene* in the rocks formed within the calcareous beds; the presence of *scapolite* in the rocks further from the contact surface, but still including bands of calciphyres.

I was unable to discover the continuation of this interesting contact on the upper slopes. I can say, however, that in the higher parts of this mass, at a height between 3000 and 3500 metres (10,000-11,500 ft) I have met neither femic rocks of the type just described, nor calcareous rocks.

Throughout the zone between the eastern limit of the basic mass and the outcrops that occur somewhat to the west of Twar and Lustung, I have not found extraneous rocks included in the noritic rocks, with the exception of the calcareous portions already mentioned present in the contact zone near Mulakor, and of the few perhaps biotitic schistose bands, observed on the left side of the Twar valley, within the tonalite. I cannot give particulars of the "amphibolitic gneisses" occurring at the western spur of confluence between the Twar and Indus rivers (right side of the lower Twar valley), and forming an outcrop of several hundred metres, as I did not stop here to make observations. It is not known if such "amphibolitic gneisses" represent schistose rocks included in the basic mass or norites deformed and laminated by the dynamometamorphism.

Two kilometres towards the east of lower Steriko (*) *amphibolite hornfelses*, without schistosity, begin to appear in patches and bands of variable dimensions (up to a few dozen square metres) within the hypersthene diorites which show considerable variations of grain. Towards Steriko the inclusions become so abundant that in places they seem to prevail on the surrounding rocks. At Steriko the geological situation is the same, but is complicated by the appearance of small acid masses, of granitic type, which I shall speak about further on. Starting from this point, the dioritic rocks and the amphibolite inclusions begin to show a certain schistosity, which is more and more evident towards the west, the rocks of the basic mass finally becoming coarse-grained *dioritic gneisses*. Under the microscope it can be ascertained that besides possessing a schistose texture these rocks lack pyroxene, either orthorhombic or monoclinic (54 PZ-23) while often poikiloblastic *amphiboles* and biotite are more abundant, and epidote significant.

The similarity between these biotitic-amphibolic, or amphibolic-biotitic rocks with gneissose texture, and the massive facies of the Twar mass, is again shown by the *plagioclase* which always maintains the same appearance and composition.

Because of the conformity of schistosity shown by the enclosing and the enclosed rocks it is not always easy to distinguish between them on the field. Under the microscope, however, the distinction is possible, at least when the enclosed rocks contain characteristic minerals, besides the minerals of the enclosing metadiorites.

About the nature of the rocks discussed above, it can be said that they are always similar, either when they are enclosed in the massive rocks or in the schistose ones. A dark patch enclosed in the hyperthene diorites a little to the east

(*) The name "Steriko" indicates three groups of dwelling-places situated at heights of 1800 m, 1950 m, and about 2050 m, that I shall call respectively lower, middle and higher Steriko.

of Steriko has been determined as an *amphibole hornfels* rich in *scapolite* (1) and containing only minor quantities of *plagioclase* 45-50% An (2) in small crystals (54 PZ-22). Nearly similar is the central part of a band enclosed in the meta-diorite and concordant with it (54 PZ-24 b), which is characterized by the great abundance of *scapolite* (mizzonite) (Plate 7, figs. 3 and 4) and by the richness of the *epidote*. The outer parts of this band on the other hand are definitely more schistose; they contain large quantities of a plagioclase 40% An, similar to that of the surrounding metadiorites, and they are rather poor in *scapolite*; this latter mineral is abundant only in connection with some *amphibolic-biotitic* layers practically devoid of feldspar (54 PZ-24).

Five hundred metres west of Tulu a great subvertical dyke about 80 metres thick striking east-north-east, interrupts the continuity of the basic rocks. It is a pegmatite, very rich in quartz, with large flakes of biotite, and includes long bands of schists and concordant streaks of epidote, so that it has a bedded appearance.

This great dyke represents, clearly, the boundary between the rocks belonging to the basic Twar mass and a formation not so well defined, characterized by strong deformations and by concordant acid veins, which forms the outcrops in the middle and lower portion of the Askore valley.

Before going on to describe this formation it is worth mentioning that, between the mouth of the Twar valley and the great pegmatitic dyke, aplitic, granitic, or other sialic dykes and veins cross the massive or schistose basic rocks of the mass. These veins are particularly abundant west of Steriko where they form a considerable network, but become rarer away from the bottom of the valley until they disappear.

In the vicinity of Steriko, other more interesting sialic developments can be observed, for within the amphibolic or amphibolic-pyroxenic rocks appear some clear pockets of *aplitic or granitic appearance* with a weak schistose texture, which pass into the common rock. Such pockets sometimes occur in the dark patches corresponding to the country rocks enclosed in the basic mass; then these patches become lighter in appearance and contain thicker amphiboles. At lower Steriko a modest *aplitic-granitic* mass, occurs almost completely without schistosity, and this extends down towards the bottom of the Indus valley and reaches a width of about 500 metres west of the village. A similar small mass also occurs east of middle Steriko.

(1) ω varies from one crystal to another and from rock to rock, lying between a somewhat broad limits (1,552-1,577).

(2) Determinations done on the albite-Carlsbad twins have given the following results:

42% An; 44% An; 48% An; 50% An.

Only in one rock, besides the andesine, have I found a plagioclase 30% An.

THE AMPHIBOLIC SCHISTS OF THE ASKORE VALLEY

West of the great pegmatitic dyke, that crosses the Indus valley almost at right angles, in the vicinity of Tulu, schists occur which are characterized by the constant abundance of amphibole. The schists extend over almost all the middle and lower basin of the Askore valley.

The high metamorphic grade and the consequent texture shown by these rocks do not permit any clear recognition of their relations with the diorites and the metadiorites of the Twar mass.

Starting from the pegmatitic dyke, and walking westwards along the Skardu-Gilgit caravan-trail one meets at first some dark *schists* which have considerable developments of *biotite* and occasional greenish bands particularly rich in epidote. They are discordantly intersected by a few *aplitic veins*. Further on *"lit par lit" bands of pegmatitic material* become more and more frequent, and a few hundred metres from the great dyke the discordant veins disappear.

Continuing towards the mouth of the Askore valley the rocks become gradually more amphibolic. The concordant sialic intercalations, which range from a few centimetres to a few decimetres in thickness, but which in some cases are thicker, sometimes resemble aplitic gneisses by the presence of flakes orientated parallel to the planes of schistosity of the amphibolitic or amphibolic-biotitic rocks.

The alternations of light and dark bands give the formation a characteristic appearance and allows it to be traced for a considerable distance in the Askore valley, and on the left side of the Indus valley, keeping a constant trend. (The bands are subvertical dipping south-east, and striking parallel to the axis of the Askore valley).

It is common enough to observe a certain enrichment of *biotite* corresponding to the planes of movement.

West of the Askore valley the rocks seem to become still richer in *amphibole* (54 PZ-26) though they always contain a remarkable quantity of plagioclase. The tectonic complexity of this zone, which continues towards the migmatitic formation of Stak, is made evident by the presence of small local folds twisted in all directions, of faults, and of faulted folds.

The frequency of the concordant acid veins diminishes, and a further increase in biotite gradually leads to the appearance of *micaschists* or paragneiss, similar, at least in appearance, to those observed in the Stak valley. This similarity becomes more definite with the occurrence of *migmatitic gneisses*.

I was not able to discover a precise boundary between the formation of the amphibolitic schists of the Askore valley and the migmatitic gneiss of Stak.

Higher still, some dark rocks, almost certainly *amphibolic gneisses*, overlay the gneisses of Stak, and it is probable that they are united with the small amphibolitic mass that occurs in the lower Stak valley.

On the right side of the middle Askore valley the moraines are very extensive and for this reason outcrops are discontinuous. The rocks that are exposed are less intensely laminated, with coarser grain, and richer in femic minerals, and consequently poorer in feldspar; but above all they differ from the amphibole and biotite-amphibole gneisses occurring in the vicinity of the floor of the Indus valley by the presence of great quantities of *garnet*.

Within these *garnetiferous amphibolites* rich in *epidote* and sometimes also containing small quantities of *scapolite* (54 PZ-34) which form the more common facies in this part of the valley, occur some small *ultrafemic* masses with coarse-grain and weak schistose texture, lacking in feldspar and having little quartz, and formed almost exclusively of *hornblende* and *garnet* (54 PZ-35). Their appearance is reminiscent of the hornblendites.

In the upper part of this slope, among the prevailing amphibolites, *mica-schists* with reddish surfaces and *migmatitic gneisses*, analogous to those that are found in the middle Stak valley, also occur. It was not possible to observe the relationship between these two different types of rocks.

About one kilometre to the north-east of the shelter in the middle valley the Stak-type gneisses occur. As I have already said, it was not possible for me to make excursions into the high Askore valley, beyond the confluence of the two principal branches, but from telescopic observations it would seem that the two slopes of the western branch at least are formed of Stak-type gneisses. This is all the more likely because further north, beyond the upper Askore valley, these gneisses occur throughout the upper Stak valley, as far as Stak-la.

CONCLUSIONS

CHEMICAL VALUES

The analytical and petrochemical data relating to the samples chosen to obtain the necessary information about the chemical composition of the rocks of the femic Twar mass are combined in the comparative Table 9.

The three rocks chosen for this purpose correspond to three different petrographic facies. A *hypersthene diorite* represents the most typical facies

TABLE 9

THE TWAR BASIC MASS.

Analysed rocks

Locality	Petrographic classification	Chemical classification according to Niggli's magmatic types
1. – The Indus valley, between Twar and Steriko.	Hypersthene diorite (the most common facies) (54 PZ-21).	*Normal dioritic type.*
2. – The Indus valley, between lower and middle Steriko.	Amphibole diorite with slight schistose texture (54 PZ-62).	Dioritic magmas: *normal dioritic* and *orbitic types.*
3. – In the canyon to the east of the village of Twar.	Hornblende-biotite-pyroxene tonalite (54 PZ-65).	*Normal quartz dioritic type.*

CHEMICAL COMPOSITION

	1	2	3
	Analyst: E. Callegari	Analyst: E. Callegari	Analyst: E. Callegari
SiO_2	53.52%	51.14%	58.49%
TiO_2	0.96	0.87	0.67
P_2O_5	0.38	0.32	0.25
Al_2O_3	18.40	19.00	17.51
Fe_2O_3	1.69	2.07	1.92
FeO	6.05	6.12	4.36
MnO	0.15	0.19	0.19
MgO	4.30	4.48	3.30
CaO	7.99	8.32	6.20
Na_2O	3.66	3.31	3.49
K_2O	1.69	2.36	2.51
H_2O+	0.77	1.46	0.66
H_2O-	0.06	0.04	0.06
	99.62	99.68	99.61

NIGGLI'S values

Twar analysed rocks	*si*	*al*	*fm*	*c*	*alk*	*k*	*mg*
1. Hypersthene diorite	145.1	29.4	34.9	23.2	12.5	0.23	0.50
2. Amphibole diorite	133.4	29.2	35.3	23.2	12.3	0.32	0.49
3. Quartz diorite	182.1	32.1	31.7	20.7	15.5	0.32	0.48
NIGGLI'S *magmatic types*							
Dioritic magmas:							
Normal dioritic type	155	30	35	21	14	0.3	0.5
Orbitic type	135	27	42	21.5	9.5	0.25	0.5
Quartzdioritic magmas:							
Normal quartz dioritic type	225	32	31	19	18	0.25	0.45

and prevails over all the central part of this plutone; the other (*amphibole diorite*) is macroscopically similar to the first, but possesses a metamorphic texture and is devoid of pyroxene; the last (*biotite-amphibole-pyroxene quartz diorite*) represents the medium type of the sialic facies prevailing in the north-eastern part of the mass.

The first two, despite differences of mineralogical composition, are chemically similar and both correspond to the *normal dioritic type* of the group of the *dioritic magmas*. The coincidence with this "magmatic type" is nearly perfect; the more important difference is met in the value *alk*, slightly lower in the rocks examined (12,5 and 12,3 instead of 14). It can thus be said that the two fundamental facies of the femic Twar mass, the hypersthene diorites with massive texture, and the amphibole diorites with more or less schistose texture are practically the same and that the amphibolitic facies derives directly from the amphibolic-pyroxenic facies by simple metamorphic transformation, without the supply of extraneous materials.

The sialic facies analyzed corresponds to the *normal quartz dioritic* type of the group of the *quartz dioritic magmas*. This rock, like the two diorites analyzed, possesses a deficiency in respect of *alk* compared with the medium characteristic value of the normal quartzdioritic type. It should be noted, moreover, that there is a tendency towards tonalitic types, as indicated by the value of *k*.

In the Twar mass, besides the analyzed rocks — hypersthene diorites, amphibole diorites and biotite-amphibole-pyroxene quartz diorites — more basic rocks — norites and amphibole gabbros — are also present and more sialic rocks, of granitic aplitic and pegmatitic type, forming patches and veins in the femic mass. Nevertheless, this plutone on the whole, shows a certain constancy of facies.

In this same chapter, in Table 5, (page 36) are reported the analytical data of another sample; the discussion of this is again found in another chapter (page 103), it being one of those amphibolitic facies which form the most common elements of the surrounding formation. It is sufficient to remark here how these amphibolites, corresponding chemically to *gabbroic types*, possess, on the average, more femic composition than the rocks injected into them which form the basic Twar mass.

ANALOGIES WITH OTHER HIMALAYAN FORMATIONS

Formations perfectly analogous to those observed by me in the Askore-Twar zone were first mapped and described by D. N. WADIA (1932, 1937), in the area of Nanga Parbat, and later by P. MISCH (1949). Other authors have made some observations on analogous formations occurring south-east of the Nanga Parbat group which, however, furnish only a few essential data about these rocks.

To give a complete picture of the geological situation encountered by the two aforesaid authors, it will be sufficient to remember that the mesozonal migmatitic gneisses (pre-Cambrian schists of Salkhala's group incompletely granitized and with a general trend NNE-SSW) which form the outer parts of the gneissic massif of Nanga Parbat, are limited towards the east and towards the west in the northern outcrops, by mesozonal amphibolites whose direction of foliation is parallel to that of the gneisses of Salkhala. Passing towards the southern outcrops the mesozonal amphibolic rocks are succeeded by corresponding rocks of the same nature but less metamorphic. In the lowest grades of metamorphism such rocks obviously belong to a *Cretaceous-Eocene volcanic formation*, represented by basaltic and also by more acid lava flows interbedded with tuffaceous and sedimentary rocks.

In the most northerly part of this area, petrographically similar to the Twar zone and the nearest to it (only the high ridge that stands above the zone of Rondu, on the left side of the Indus river, divides the two zones), intrusive basic rocks are very common, among which the *norites* and *hypersthene diorites* predominate.

P. MISCH's observations show that close to the gneissic massif the noritic rocks are "intimately interbedded and interfolded with the paragneisses and migmatitic gneisses" and that "both rock types, e. g., the norite bodies and the gneiss massif, have here participated in the same process of tectonic deformation and of crystallization accompanied by some granitization" (1949, p. 217).

In the following pages a few words will be said about the presence, inside the norites, of more small sialic masses or pockets (thought by P. MISCH to be a product of a process of static granitization).

More interesting is the opinion of D. N. WADIA (1932), confirmed by P. MISCH, that these basic masses are the intrusive analogues of the rocks of volcanic origin in which they are generally found.

I think that the brief account given above is sufficient to illustrate the undeniable analogies existing between the formations occurring in the area of Nanga Parbat and those in the area mapped by me. Just as the migmatitic gneisses of the Stak basin (see preceding chapter) represent the direct continuation of the gneissic formation of the Nanga Parbat group, so the amphibolites and the more or less schistose femic masses which form the boundary of this group towards the east continue across the mountains above Rondu without much change in their main trend until they reach the right bank of the Indus river in the Askore-Twar zone. I recall that this trend is roughly NE-SW, dipping towards south-east (at least between Twar and the divide between the Askore valley and the Stak valley) and is perfectly parallel to the one observed in the migmatitic gneisses occurring in the lower branch of the Stak valley.

PETROGENESIS

As a result of observations made in the field and of petrographic and chemical analysis of the Twar rocks, we are now in a position to appreciate both analogies and differences between the various parts of this mass.

These are the main differences concerning the chemical, mineralogical and textural characteristics:

(1) There is a constant variation of composition in the central portion of the mass, ranging from the femic types at the bottom of the valley to the sialic types at the top.

(2) In the eastern outcrops, when the surrounding rocks are calcareous, there are femic (amphibolic) differentiations.

(3) In the western portions, the rocks become more and more metamorphic (amphibolic gneisses and amphibolites).

Such are the main modifications of the most common facies, which is to be regarded as the original rock, unaffected by any chemical or mineralogical tranformation. They are caused by the following processes.

Gravitational differentiation and autometasomatism.

In the central part of the mass (which is also the fundamental portion of this femic pluton) both the more femic and the gradually more sialic rocks bear plagioclases of characteristic appearance and of identical composition (40-50% An) and the same femic minerals (pyroxenes, amphiboles and biotite).

The difference between the femic and the sialic rocks, however, does not depend entirely on the ratio between such minerals which they have in common, but also on a gradual increase of potash-feldspar and quartz in the more sialic rocks.

The difference in composition of these rocks is very probably the result of two successive stages in the process of crystallization. Firstly, a moderate concentration of femic minerals in the lower layers of the magmatic basin caused — through gravitational differentiation — the crystallization of rocks bearing considerable quantities of orthorhombic and monoclinic pyroxene; and correspondingly, in the higher layers it caused the formation of rocks in which the plagioclases are more and more abundant. This process brought about some differentiation; but this is not very sharp, and in fact in all the facies the plagioclases show considerable similarity of composition. It is to be inferred that in this first stage of differentiation there must have been little variation in the nature of the femic minerals at the various levels in the mass, and that the differences of mineralogical composition depended essentially on the varying quantitative ratio between the sialic and the femic minerals.

There was then a second stage, when the more leucocratic rocks formed as a result of magmatic differentiation, became soaked by sialic materials, especially potash. These materials replaced and transformed more or less extensively the previous minerals, as shown by the fact that the potash-feldspar (microperthite) appears in irregular patches which enclose fragments of plagioclases. The transformation of the pyroxenes into amphiboles and of these into biotite is also to be explained by the same metasomatic processes. As a final result of the supply of these materials rich in silica and alkali, the rocks underwent a further and more pronounced evolution towards more sialic types.

As these metasomatic transformations are confined to the upper layer of the intrusive mass, and affect the surrounding rocks only to a depth of a few metres, one would think that the materials in question represent the final residue of the crystallization of the mass (autometasomatism).

Therefore the growth of the femic minerals in an order corresponding to the Bowen discontinuous reactions series should only in part be attributed to a process of fractional crystallization (orthorhombic pyroxene→monoclinic pyroxene); while the formation of the amphiboles and of the biotite should be the result of an autometasomatic process.

Before passing on to examine the other causes that have contributed to the alteration of the original facies of these femic rocks, I would like to mention those small light sialic masses or patches that occur not unfrequently inside the basic rocks, especially in the vicinity of Steriko (above p. 45), which could have been formed by similar processes. I recall that, having made some rapid observations in this zone, I did not pay particular attention to the relationship existing between these sialic patches and the surrounding basic rocks, or to the basic rocks and the very frequent thin veins of aplitic and pegmatitic appearance which cut the femic Twar mass in all directions. I treat this subject in this chapter, because P. MISCH (1949) has fully discussed the genetic characteristics of similar rocks, occurring in the noritic and metanoritic masses of the Nanga Parbat group. According to MISCH (p. 678), these "small bodies, pockets and patches which spread out irregularly in the basic rocks" could be the products of a process of static granitization (post-kinematic) of the metanorites. "The granitized rocks", compared with the original basic rocks "are enriched in plagioclase and quartz, impoverished in mafics; much hornblende has been replaced by biotite, and some potash-feldspar has formed"; the plagioclases (more sodic than in the basic rocks) and also the potash-feldspar, when present, forms "replacement porphyroblasts enclosing small relict grains". The passage between granitized rocks and basic rocks is generally gradual. The granitization should have occurred by the "addition of alkali and silica from a more distant source". "Sodium is commonly the main alkali added... Potash-feldspar is often absent, and only locally has it formed in larger quantities".

For the reasons already mentioned I am not able to assert that the small sialic masses or patches present in the zone surveyed by me correspond in composition and texture to those studied by P. MISCH. It is interesting, however, to note how in different parts of the same dioritic-noritic mass (or in different masses of similar origin and composition) some transformation has occurred depending on the introduction of alkaline materials rich in soda, or potash.

CHANGES DUE TO THE ASSIMILATION OF SURROUNDING ROCKS.

Transformation by syntexis is limited in the Askore-Twar zone, and has been observed only at the contact with the limestones which occur as thick beds crossing the Indus valley at right angles near the village of Mulakor. In the preceding pages the relationship bewteen the rocks of the femic Twar mass and these limestones has been described and it is sufficient to recall now that the tonalitic rocks that occur in the eastern part of the mass in question, pass, towards the contact with the limestones, to increasingly darker amphibolitic rocks. Close to the limestones the grain coarsens occasionally to pegmatitic type. The calcareous beds, initially continuous and regular, become reduced to pieces of marble or hornfelses constituting the elements of a great breccia, with a matrix of amphibolic gabbro which, however, maintains the same general trend.

Features giving a clear indication that the amphibolic gabbros occurring in the vicinity of Mulakor owe their actual composition to assimilation of the calcareous rocks are: the intimate field relations of the plutonic rocks with the calcareous rocks; the exceptional size of the minerals of the intrusive rock (caused probably by the abundance, during crystallization, of CO_2 derived by the progressive decomposition of the carbonatic rocks); the cloudiness of the plagioclases; the presence of epidote; the abundance of calcite, and often also of sphene; and the sporadic presence of partially altered scapolite.

The relationship between the intrusive rocks and the surrounding rocks and the petrographic phenomena observed are similar to those described by B. ZANETTIN (1956) and by others (D. COLBERTALDO, 1940) along the outer parts of the granodioritic tonalitic Adamello mass (Central-Eastern Alps), and interpreted on field and laboratory evidence as the result of assimilation processes.

In contrast, no significant transformation has been observed close to the more common surrounding rocks, that is the fine-grained amphibole, or amphibole-epidote gneisses. Similarly, the intrusive femic mass has produced visible thermal effects only in relation to surrounding rocks of calcareous composition which are transformed to calc-silicate hornfelses, while the fine-grained amphibole or amphibole-biotite gneisses have remained practically unaltered. The absence of normal contact aureole at the boundary of the femic mass is easily understood because the surrounding rocks have a composition very similar to those of the rocks injected into them.

It may be added that in the eastern part of the area, near the northern boundaries of the basic mass (where the more acid facies, rich in potash-feldspar occur), the fine-grained amphibolitic gneisses of the surrounding rocks (54 PZ-69) have been subjected to the introduction of potash-feldspar that has irregularly soaked and replaced the pre-existing plagioclases.

The same effects of thermal metamorphism and syntexis apply also to the numerous lenses of variable size enclosed in the noritic diorites, or in the corresponding metadiorites of the zone, in the neighbourhood of the village of Steriko (the only zone in which the enclosed rocks have been observed closely).

Judging from the nature of the few samples collected, one could say that the more frequent lenses are represented by originally calcareous types, which have been successively altered, by the united action of regional metamorphism and of thermal metamorphism, to amphibolic hornfelses rich in scapolite (54 PZ-22).

Dark rocks with well developed amphibole are formed by the assimilation of these enclosed rocks, in which small quantities of scapolite persist. They are similar on the whole to the rocks observed in the proximity of the limestones of Mulakor. In all probability those characteristic dark patches with large amphiboles, which are very frequent inside the metanorites, west of Steriko, are also attributable to the assimilation of included calcareous rocks.

Such a process is real and not hypothetical in the zone surveyed by me, as is demonstrated, on a small scale, by an enclosed rock (54 PZ-24) whose core is formed exclusively of scapolite, amphibole, biotite and epidote while towards the periphery appear some feldspars, similar to those of the enclosing rocks, and formed firstly as layers inside the above mentioned minerals and later becoming more abundant. At the same time the scapolite alters and disappears.

The prevalence of inclusions of calcareous composition can be more apparent than real, since the presence of pieces of amphibolitic gneisses belonging to the surrounding formations can easily escape a rapid survey, because of the close similarity between enclosing and enclosed rocks. This similarity is accentuated by the fact that in the zone of Steriko the enclosing rocks also have a schistose texture.

CHANGES DUE TO REGIONAL METAMORPHISM.

As mentioned at the preceding pages, the basic rocks of the Twar mass have been subjected to more or less intensive trasformations due to regional metamorphism. Its intensity is gradually increased from east to west and reaches its maximum value at the zone of transition towards the migmatitic gneisses of Stak.

At the eastern central part of the basic mass the effects of the metamorphism are not very evident; at the most, to moderate metamorphic actions can be ascribed the homogeneous composition of the plagioclase crystals, either those of the massive facies or those of the oriented or schistose one, and some changes of pyroxenes into amphiboles.

On the contrary, west of Steriko where the metamorphism has acted with major intensity, the characteristic femic minerals of the fundamental facies of the basic mass — i. e., rhombic pyroxene, monoclinic pyroxene, hornblende — are absent, and the femic minerals are represented only by amphibole accompanied eventually by biotite and epidote. It means then, that a complete transformation of the pyroxenes is present.

Proceeding westwards the intensity of the metamorphism increases very rapidly, the rocks becoming increasingly schistose. Near the village of Tulu the metamorphism has reached a degree corresponding to the upper mesozone (the original labradoritic plagioclase has broken down into oligoclase at about 30% An and epidote) and in the Askore valley there occur rocks of lower mesozone (this is where the garnet makes its appearance).

I cannot affirm definitely that the rocks occurring in the Askore valley (amphibole-epidote or amphibole-epidote-biotite gneisses, garnetiferous amphibolites etc.), represent the metamorphic products of noritic rocks (in the areas of Nanga Parbat (P. MISCH, 1949) the noritic rocks are in contact with migmatitic gneisses of Stak type), but, in the discussion, I associate them together, because, I found no evidence that could justifiy my thinking that they are the metamorphic products of the country rocks.

The presence of amphibolites with scapolite and of small, extremely femic masses (very similar to the hornblendites in appearance, but garnetiferous) leads me to think that the original rocks could correspond to those that actually occur between Steriko and Tulu (intrusive femic rocks enclosing bands of hornfelses or amphibolitic gneisses of calcareous origin).

On present knowledge, the problem is irresolvable in this zone, because, as it has been mentioned above, the intrusive rocks and the most common types of surrounding rocks possess very similar chemical compositions so that under high metamorphic conditions, they would be altered to rocks of the same type.

As I have already said in the preceding paragraphs, one of the most evident characteristics shown in the field by the amphibolites and by the amphibolitic gneisses occurring west of Tulu, is the strong deformation, accompanied by an alternation of dark amphibolic rocks with thin bands of aplitic appearance. For the reasons already stated, my investigations in this particular zone were limited to the recognition of the main petrographic facies and to the observations of their more evident characteristics; therefore I am not able to discuss the genesis of these leucocratic "bands" interbedded with the dark amphibolites. I only want to recall here the already cited hypothesis of P. MISCH (1949) according to which the presence of sialic bands is to be attributed to a limited process of synkinematic granitization on the amphibolitic formation (1).

According to MISCH, the biotitization of the amphibolites (repeatedly ascertained by me, especially in relation to the surface of differential movement at the junction between clear and dark bands) would happen where they are in contact with granitized bands.

According to P. MISCH the metamorphism of the basic Cretaceous-Eocene rocks and, therefore, also the "synkinematic" granitization, is Early Tertiary. The "static" granitization that has produced "patches and pockets" in the norites and metanorites is successive to the metamorphism.

(1) According to P. MISCH the same granitizing materials that have acted on the pelitic rocks of Salkhala's series causing the formation of the migmatites of Nanga Parbat (and of Stak valley) have also acted on the amphibolites.

III

THE SKOYO - TURMIK ZONE

A gneissic plagioclasic mass occupies nearly all the right side of the Indus valley from the mouth of the Turmik valley westwards to the height of Skoyo village (which is situated on the left side of the Indus river). In its more westerly part, that is above Skoyo, the northern limit of the mass passes a few hundred metres under the crest separating the Indus valley from the Turmik valley and crosses it where this descends, forming the divide between the two valleys. Although the plagioclase gneisses also occur on the right side of the lower Turmik valley, they do not reach the bottom of the valley, but rise near the mouth of the valley, where the surrounding rocks constitute a wedge that penetrates some distance into the gneissic mass.

I am not able to give information about the southern limit of the mass in question because my field observations were limited to the right side of the Indus river.

On the whole, the area occupied by the plagioclase gneisses, in the zone mapped by me, is not more than 30-40 sq. km (on the surface).

The whole zone where these gneisses outcrop is easily examined, especially in the higher parts where the rocks are often covered with a thin layer of decayed soil. In the lower parts, corresponding to the line of the Skardu-Gilgit caravan-trail, the rocks are even better exposed and can be examined in detail over large areas.

GEOLOGICAL CONDITIONS AND PETROGRAPHIC FEATURES

The mass of plagioclase gneisses occurring between Skoyo and the Turmik valley does not have neat limits in respect of the surrounding rocks because of an agmatitic border of considerable thickness. Firstly we shall consider the surrounding rocks that have not suffered appreciable variations of their original chemical composition by the processes responsible for the formation of the gneissic mass. These rocks occur outside the agmatitic border.

THE COUNTRY ROCKS

The surrounding rocks are represented by some members of the volcanic-sedimentary series whose outcrop extends from the zone of Twar to the Shigar valley. The petrographic values and the relative interpretation of these rocks are reported in the chapter concerning the zone of the Turmik valley. Here it will be sufficient to give only some details of their petrographic character.

Towards the west the plagioclase gneisses are separated from the dioritic-noritic Twar mass by a diaphragm of amphibolic schistose rocks, slightly more than 1 km thick. As can be seen from the descriptions reported in the chapter concerning the Twar zone , the country rocks occurring near the valley floor are made of *amphibole-epidote gneisses* (54 PZ-18) alternating with *calcareous rocks*. In the higher parts, however, above the 3,000 metre level (10,000 ft), rocks of argillaceous or argillaceous-calcareous origin are often found represented by fine-grained *micaschists* and *micaceous schists* rich in *anthophyllite* (54 PZ-71) interbedded with *chlorite-schists* (54 PZ-72) *calc-schists, actinolite-schists* (54 PZ-74) and *micaschists* which are sometimes smeared with thin light amphiboles with radial patterns (Garbenschiefer).

In the east, on the right side of the lower Turmik valley, north of Dasu, the country rocks are represented by *basaltic rocks*, more or less deeply weathered (54 PZ-89, 90, 91) and locally deformed by dynamic actions, and by *arenaceous phyllites* sometimes mylonitized or blastomylonitic (54 PZ-87). Similar rocks are also found on the opposite side of the valley.

In the north, the surrounding rocks are always very basic above 3,000 metres (10,000 ft) and correspond to *amphibolites*, *prasinites*, *amphibolitic gneisses*, with intercalations of *tremolite and actinolite-schists* (54 PZ-93, 94, 95, 96, 97, 98, 99, 100), and of *micaceous amphibolites* (54 PZ-101). Towards 4,000 metres (13,000 ft) these rocks change to fine-grained acicular *epidote-amphibole gneiss*.

On the whole the more common country rocks correspond to *amphibole-epidote gneisses* rich in plagioclase and to *biotite-epidote gneisses*. The more basic facies occur towards the northern limit of the mass.

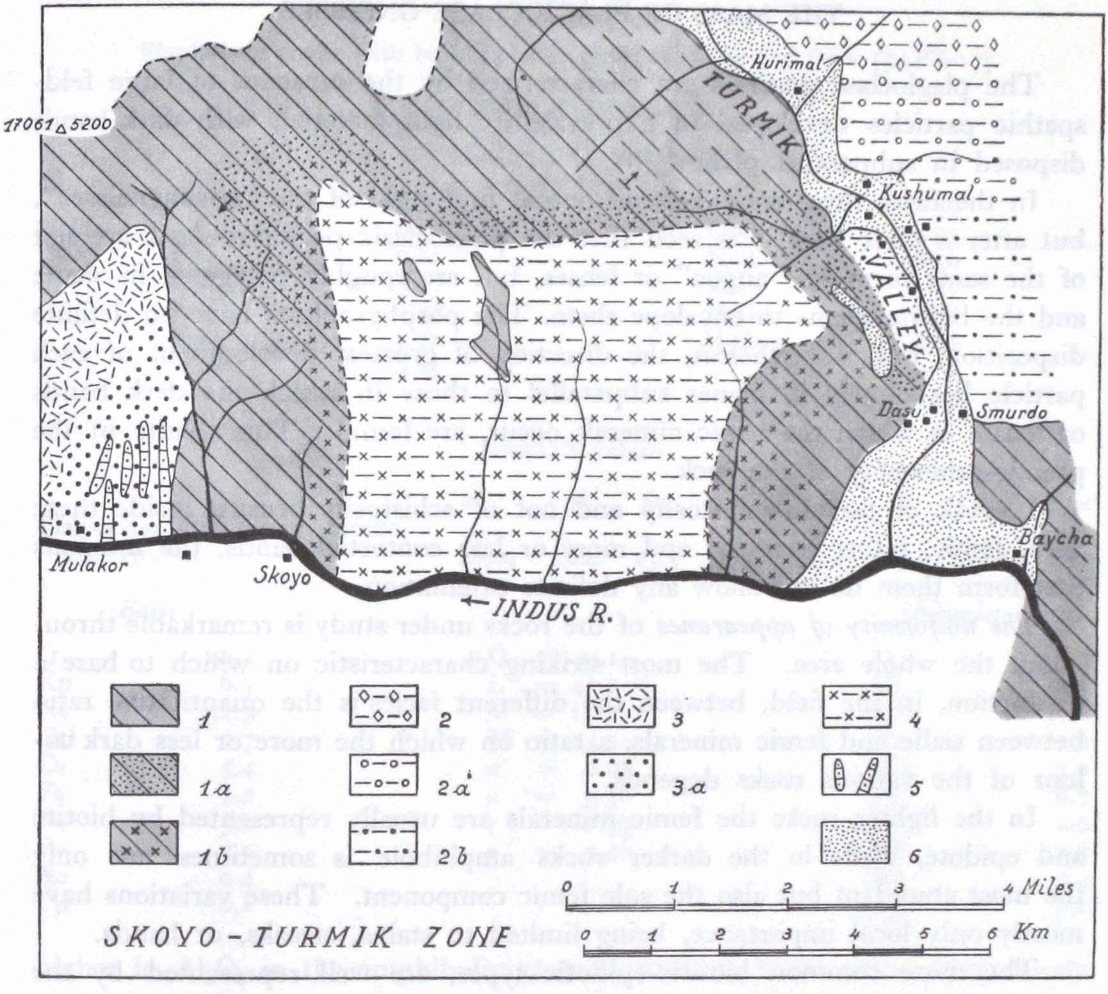

Fig. 6 - Geological sketch-map of the Skoyo-Turmik valley zone.

1, 1 a, 1 b - Cretaceous basic schists:

1 - Amphibolites, epidote-amphibolites, biotite-amphibole gneisses etc.;

1 a - Basic schists with mica or amphibole porphyroblasts;

1 b - Agmatites with elements of basic schists cemented by plagioclase gneisses.

2, 2 a, 2 b - Semimetamorphic Cretaceous schists:

2 - Phyllites with carbonatic porphyroblasts;

2 a - Conglomeratic schists;

2 b - Sandstone phyllites.

3, 3 a - Basic intrusive rocks (Twar mass):

3 - Quartz diorites and pyroxene-bearing biotite-amphibole granodiorites;

3 a - Gabbrodiorites and amphibole gabbros.

4 - Plagioclase gneisses.

5 - Marbles, calciphyres and calc-hornfelses.

6 - Moraine, alluvium and debris.

THE MASS OF PLAGIOCLASE GNEISSES

The plagioclase gneisses are characterized by the presence of large feldspathic particles developed in a prevalently light material, with dark bands disposed in subparallel planes.

In the field, these rocks remind one at first sight of the "augengneisses", but after a close look it is seen that the plagioclasic porphyroblasts are not of the same form as " augen" or lenses, but are roughly polygonal in shape and the biotite seems to envelope them. The porphyroblasts have no definite disposition, but, nevertheless, the direction of greatest development of each particle lies mostly in planes subparallel to those in which the dark bands or lenses in which the femic minerals occur, are found. This results in the pseudo-schistosity of the rock.

I speak of pseudo-schistosity and not of schistosity because inside these dark, femic, rather irregular and more or less contorted bands, the minerals that form them do not show any definite orientation.

The uniformity of appearance of the rocks under study is remarkable throughout the whole area. The most striking characteristic on which to base a distinction, in the field, between the different facies is the quantitative ratio between sialic and femic minerals, a ratio on which the more or less dark colour of the various rocks depends.

In the lighter rocks the femic minerals are usually represented by biotite and epidote, while in the darker rocks amphibole is sometimes not only the most abundant but also the sole femic component. These variations have mostly only local importance, being limited to stains, streaks, or bands.

The more common biotitic-epidotic types, are well represented by the sample 54 PZ-17. In Table 10 is given the chemical analysis and the relative petrochemical data which shows the sialic and decidedly sodic character of this rock (Na_2O = 6,56%) and the low value of *k* (0,15). This rock cannot be compared with any of the "magmatic types" of NIGGLI, particularly because the value of *k* is excessively low for persilicic rocks.

In the upper part of the western outcrops besides the stains, patches and pockets of rocks (54 PZ-75 a) almost black because of the lack of feldspar, the most common type of the rock also has a colour little darker than elsewhere (54 PZ-75).

A chemical analysis was made of this last sample in order to establish if there is any difference in composition between the biotitic-epidotic types and these biotitic-epidotic-amphibolic types. The results obtained (Table 11) show that, apart from the contents being a little lower in SiO_2 and a little

TABLE 10

Plagioclase gneiss with biotite and epidote; *to the west of Dasu* (54 PZ-17).

CHEMICAL COMPOSITION

(Analyst: C. Viterbo)

SiO_2	68.39%	MgO	1.49
TiO_2	0.52	CaO	4.03
P_2O_5	0.11	Na_2O	6.56
Al_2O_3	13.17	K_2O	1.81
Fe_2O_3	1.02	H_2O+	1.08
FeO	1.72	H_2O-	0.08
MnO	0.05		
			100.03

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Plagioclase gneiss with biotite and epidote	267.9	30.4	23.3	16.9	29.4	0.15	0.62	0.72

Basis				*Molecular Norm*	
Q	44.1	Q	= 44.1	Q	12.9
Kp	6.3	L	= 41.7	Or	10.5
Ne	34.7	M	= 13.7	Ab	57.8
Cal	0.7	M′	= 14.2	An	1.2
Cs	5.4	π	= 0.01	Wo	7.2
Fs	1.2	μ	= 0.36	En	6.7
Fo	5.0	γ	= 0.39	Hy	2.0
Fa	2.1	α	= 3.46	Mt	1.2
Ru	0.4			Ru	0.4
Cp	0.1			Cp	0.1

higher in Al_2O_3 in the amphibolic gneisses, the two facies correspond nearly perfectly. The content in Na_2O is practically the same, whereas K_2O, very scarce in the biotitic facies, shows still lower value in this rock, resulting in an even lower value of *k* (0,11).

Another variable characteristic of these plagioclase gneisses is shown by the diversity of the dimensions of the feldspathic crystals. In this case the variations are rather small and seem to occur slowly and gradually. There is usually an increase of the size of the plagioclases passing from the outer parts of the mass towards the inner parts.

Much more rare, and limited to small outcrops, is the weakening, and even the disappearance, of the schistosity of the rock, which, at the same time, tends to assume a lighter colour. This fact has been observed only in the outer parts of the mass (54 PZ-92), or directly inside the agmatitic belt.

TABLE 11

Plagioclase gneiss with biotite epidote and amphibole; *western part of the mass, at a height of* 3900 *m* (12,800 *ft*) (54 PZ-75).

CHEMICAL COMPOSITION

(Analyst: C. Viterbo)

SiO_2	65.65%	MgO	1.99
TiO_2	0.47	CaO	4.61
P_2O_5	0.19	Na_2O	6.70
Al_2O_3	15.46	K_2O	1.31
Fe_2O_3	1.18	H_2O+	0.82
FeO	1.72	H_2O-	0.11
MnO	0.04		
			100.25

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Plagioclase gneiss with biotite-epidote-amphibole	245.9	34.1	19.9	18.5	27.5	0.11	0.56	0.93
Adamellitic type	300	37.5	22.5	13.5	26.5	0.45	0.3	
Normal granodioritic type	280	39	22	17	22	0.45	0.4	

Basis				*Molecular Norm*	
Q	42.9	Q	= 42.9	Q	10.1
Kp	4.6	L	= 45.2	Or	7.7
Ne	35.7	M	= 11.3	Ab	59.5
Cal	4.9	M′	= 11.9	An	8.2
Cs	4.0	π	= 0.1	Wo	5.3
Fs	1.2	μ	= 0.36	En	5.5
Fo	4.1	γ	= 0.35	Hy	1.9
Fa	2.0	α	= 3.30	Mt	1.2
Ru	0.3			Ru	0.3
Cp	0.3			Cp	0.3

The values obtained by the chemical analysis of sample 54 PZ-92 are shown in Table 12. Also this facies of the plagioclase gneisses can be considered in the same way as the other analogous analysed rocks. The only remarkable difference is shown by the value of K_2O, slightly higher than in the schistose facies, but insufficient to compare it to the *normal trondhjemitic* type from which it differs also in the excessively high value of *c*.

I have been unable to investigate fully the rocks of the central parts of the plagioclase gneisses mass, but I think that they are not different from those of the areas already known because the scree collected at the foot of the deep clefts that extend the full height of the mass (from the beds of the Indus river, at 2,000 m (6,500 ft) to above 4,000 m (13,000 ft)) is identical to the rocks existing in the other parts of the mass.

Apart from the variations, always slight, which result from the different quantitative ratio between leucocratic and melanocratic minerals, the nature

TABLE 12

Plagioclase gneiss with biotite and epidote; *at the eastern contact of the mass in the Turmik valley* (54 PZ-92).

CHEMICAL COMPOSITION

(Analyst: C. Viterbo)

SiO_2	69.19%	MgO	0.44
TiO_2	0.21	CaO	3.25
P_2O_5	0.36	Na_2O	6.06
Al_2O_3	14.24	K_2O	2.12
Fe_2O_3	1.25	H_2O+	1.60
FeO	0.87	H_2O-	0.06
MnO	0.03		
			99.68

NIGGLI'S values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Plagioclase gneiss with biotite and epidote	322.5	39.1	10.9	16.3	33.7	0.19	0.28	1.49
Normal trondhjemitic type	370	42	12	11	35	0.25	0.3	

Basis				*Molecular Norm*	
Q	49.3	Q	= 49.3	Q	19.1
Kp	7.6	L	= 44.1	Or	12.7
Ne	33.2	M	= 6.2	Ab	55.3
Cal	3.3	M′	= 6.5	An	5.5
Cs	3.0	π	= 0.07	Wo	4.0
Fs	1.3	μ	= 0.13	En	1.2
Fo	0.9	γ	= 0.46	Hy	0.5
Fa	1.0	α	= 9.47	Mt	1.3
Ru	0.1			Ru	0.1
Cp	0.3			Cp	0.3

of femic components or the grain of the rock, the petrographic character is always the same for all the facies that constitute the plagioclase gneisses mass. (1).

The large plagioclasic crystals (the potash-feldspar is always absent) which represent in volume about one half of the minerals of the rocks considered,

(1) A detailed description of the different rocks of this mass can be found in C. VITERBO & B. ZANETTIN, 1959.

are separated by a rather fine aggregate formed by *quartz*, *plagioclase*, *biotite*, *epidote*, *muscovite* and green *hornblende*. The femic minerals generally tend to separate themselves and form patches in which quartz and plagioclase are very scarce. Consequently, in the quartzose-plagioclasic portions the femic minerals are rare. Besides such patches formed by association of femic or sialic minerals of different nature, there are larger patches, formed only of *quartz*, no longer in small particles, but in crystals of considerable dimensions (Plate 10, fig. 1).

It can be said therefore that in contrast to the remarkable increase of some components such as plagioclases, quartz and sometimes, with smaller crystals, biotite and epidote (and hornblende), there is the presence of fine aggregates formed by the reunion of the same minerals (Plate 11, fig. 4).

The large plagioclasic crystals, of somewhat uniform composition running, through the different rocks studied, between 14% and 20% An (1), correspond to porphyroblasts, often with irregular borders, grown in the fine aggregate of the matrix, the nonfeldspathic components of which may remain enclosed in the plagioclases. The most characteristic feature of all the plagioclasic porphyroblasts of these rocks is the *abundance of minerals enclosed in them*, which gives them a poikiloblastic appearance (Plate 8, figs. 1, 2, 3). Despite the richness of the inclusions, the plagioclases are always clear (Pl. 8, fig. 1).

The *enclosed minerals* are of different nature and dimensions. The more abundant are nearly always *muscovite* and *epidote*, but *quartz*, *biotite* (Plate 8, figs. 1, 3) and, in the amphibolic rocks, *amphibole* (Plate 9, fig. 3) are also common. Some of these inclusions are disposed according to particular directions of the plagioclasic host, (composition planes of twinning and planes of cleavage) (Plate 8, fig. 4) whereas others have almost casual dispositions. The orientated inclusions are always represented by fine flakes of *muscovite* (or sericite) and by particles of *epidote* in well formed regular crystals (Plate 8, fig. 4); the other minerals mentioned above, and some more developed particles of muscovite and epidote, have no particular orientation. Quartz, biotite and amphibole as inclusions are subjected to progressive alteration or replacement.

The *quartz* enclosed in the porphyroblasts does not have a uniform distribution. It is sometimes concentrated in the central parts of the large feld-

(1) In general γ' is a little higher than, of the same as ω_q, and the optic sign is negative. Rarely, especially along the margin of the porphyroblasts, the optic sign is positive. Only in one case γ' is lower than ω_q.

spars, but it is more often abundant at the edges. Some inclusions of quartz have zig-zag edges corresponding to those parts of the grains that cut the composition planes of the twinned plagioclases. Around some quartz particles the plagioclase has a slightly different composition, as can be seen by the variation of birefringence (Plate 10, figs. 2 and 3).

The quantity of *biotite* enclosed in the large plagioclases varies from crystal to crystal and from rock to rock. The smaller flakes often show a weakness of the pleochroism and of the birefringence, and seem, at last, to fade away to the plagioclase (Plate 9, figs. 1, 2, 3).

In some rocks large poikiloblastic particles of muscovite and of biotite cut across either the plagioclase porphyroblasts or the groundmass (Plate 9, fig. 4; Plate 8, fig. 4).

The enclosed *amphibole* also undergoes, like the biotite, a gradual discolouration and transformation, but it is not easy to follow the transition. The *hornblende* is present as an inclusion only in the amphibolic rocks (that is, in those in which the amphibole is one of the common femic components) and its frequency is proportional to the abundance of hornblende in the rock.

Often, in the large plagioclases, sections with different orientation can be distinguished, so that the porphyroblasts appear to be formed by the amalgamation of different particles (Plate 10, fig. 4). Grains of quartz, sometimes accompanied by biotite and by epidote, are often placed at the boundaries between sections which have different orientation. In some cases stripes of quartz of similar appearance cross porphyroblasts of greater homogeneity.

The small *albitic-oligoclasic plagioclases* about 15% An (1), which with grains of *quartz* and with a small quantity of *femic minerals* form the groundmass, do not show clear boundaries between particles, so that each crystal possesses an orientation a little different from that of the contiguous crystal. Thus the aggregates very rich in plagioclases sometimes assume the aspect of a continuous irregular feldspathic patch enclosing the other minerals (Plate 10, fig. 4).

This aspect, not always clearly seen in the more common rocks, assumes particular importance in the *plagioclase gneisses rich in amphibole* (54 PZ-75 a) which occur in the north-western portion of the mass, at a height of about 4,000 metres (13,000 ft). In such rocks the fine sialic minerals of the matrix form large light patches, macroscopically similar to the plagioclasic porphyroblasts. In every single plagioclase granoblast the orientation varies gradually

(1) $\gamma' \geq \omega_q$; generally the optic sign is positive, but sometimes negative.

from one point to another, and passes, without a break, to the adjacent granoblast, so that the limit between each particle is practically indistinguishable.

In some cases a section of this patch, usually the central part, shows more homogeneity than the remaining parts, and form a true plagioclasic porphyroblast which fades away laterally in the fine aggregate.

In these fine-grained patches, besides, great quantities of *muscovite* and *epidote* are enclosed, in the same way as in the porphyroblasts.

THE AGMATITIC BELT

Wherever observations have been made at the periphery of the mass, the agmatitic belt that separates the plagioclase gneisses from the unaltered surrounding rocks appears to be continuous. Examination of this belt from the centre outwards has shown *pieces and bands of surrounding rocks* enclosed in the plagioclase gneisses. At first these inclusions are rather rare and of small dimensions, sometimes with transitional boundaries in relation to the enclosing rock, then gradually they become larger and more numerous until they become prevalent over the plagioclase gneisses. In some places the granitoid rocks form isolated stains inside the surrounding fine-grained basic schists. These last are, in their turn, crossed by a network of sialic veins.

Towards the outside the surrounding rocks have suffered local mineralogical transformations, generally shown in the field by the unusual development of some phyllosilicates, like *micas* and *chlorites*, or *acicular amphiboles*, or, more rarely, by the presence of small feldspathic patches.

The greater thickness of the agmatitic belt is seen in the south-eastern part, where it is succeeded by a zone of exceptional extent crossed by acid veins; this zone is formed by the surrounding rocks that, as a wedge, penetrates the mass of the plagioclase gneisses on the western side of the confluence between the Turmik and Indus rivers, and by the similar terrains that occur on the opposite side of the Turmik valley, south of the village of Smurdo (and extending as far as and beyond Baycha in the Indus valley).

Further north the agmatitic belt (partially covered by the long morainic belt that runs on the right side of the Turmik valley, parallel to its axis and to the agmatitic belt), is narrower, and absent, or very limited, is the portion intersected by acid veins. In fact beyond the above mentioned morainic belt, which is 200-400 metres (600-1,300 ft) wide, occur the surrounding rocks (rich in large micaceous flakes), corresponding to the outermost part of the marginal belt. These latter rocks reach the valley bottom near the village of Kushipa, but do not appear on the opposite side, where the rocks are of normal unaltered type.

Along the northern limit of the mass, where the surrounding rocks are mainly *basic* (amphibolites, prasinites, amphibolic gneisses etc.), the marginal belt is not wide and seems to consist only of agmatites which occur on the right side of the little valley, running parallel to this belt, that leads into the Turmik valley near the village of Kushumal.

The marginal belt is also narrow at the *western boundaries* of the sialic mass, where the schists, more or less altered and crossed by light dykes and veins of aplitic appearance, contain *patches* of light fine-grained aplitic rock and, in the higher part of the outcrops, a small mass of granitic-aplitic appearance.

In general it can be said, therefore, that in the agmatitic formation the cement, made up of plagioclase gneiss, shows relative uniformity in composition and aspect, while the basic schists, as element to be cemented, are somewhat varied in nature.

In the outcrops crossed by the Skardu-Gilgit caravan-trail, in the *south-eastern part* of the marginal belt, the *rocks enclosed* in the plagioclase gneisses are mostly *fine-grained biotite-epidote gneisses* of *dioritic* composition (Table 13). These rocks (54 PZ-17a) are formed with a relatively fine aggregate of *quartz* and *sodic plagioclase* (not exceeding 10% An) (1) in which orientated *biotite* flakes and grains of epidote are uniformly scattered. On the other hand the *muscovite*, with large, though rare poikiloblastic flakes, sometimes crosses the schistosity of the rocks (Plate 11, fig. 1).

Of much more different nature are the enclosed rocks observed *further north*, in the valley which comes down from the west to Dasu, running nearly parallel to the boundary between the gneissic mass and the northern side of the wedge of fine-grained basic schists that penetrates into it.

Most of the enclosed rocks correspond to *actinolite-schists* with more or less well-developed acicular particles (54 PZ-80, 81), but in some cases large poikiloblastic flakes of emerald green colour, corresponding to micas of phengitic type are developed in the amphibolic aggregate (Plate 14, fig. 1). Small plagioclasic particles that often enclose part of the acicular radial aggregates of actinolite without causing displacement of the needles, have also been detected. Similarly, *talc-schists* are frequently found in which particles of pyrite with perfect cubic shape often develop (54 PZ-82).

(1) $\gamma' < \omega_q$; the optic sign is always positive. The maximum extinction angles of the albite twins vary between 9°-12° = 8-11% An.

TABLE 13

Biotite-epidote gneiss; *to the west of Dasu* (54 PZ-17 a).

CHEMICAL COMPOSITION

(Analyst: C. Viterbo)

SiO_2	57.74%	MgO	3.00
TiO_2	1.12	CaO	5.53
P_2O_5	0.31	Na_2O	4.11
Al_2O_3	17.25	K_2O	2.63
Fe_2O_3	2.62	H_2O+	1.53
FeO	3.83	H_2O-	0.09
MnO	0.09		
			99.85

NIGGLI'S values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Biotite-epidote gneiss	165.9	29.2	36.6	17.0	17.2	0.33	0.58	0.46
Normal dioritic type	155	30	35	21	14	0.3	0.5	

Basis				*Molecular Norm*	
Q	35.2	Q	= 35.2	Q	1.9
Kp	11.0	L	= 44.1	Or	18.3
Ne	21.7	M	= 19.6	Ab	36.2
Cal	11.4	M'	= 20.7	An	19.0
Cs	2.1	π	= 0.25	Wo	2.8
Fs	2.7	μ	= 0.52	En	13.6
Fo	10.2	γ	= 0.10	Hy	4.4
Fa	4.6	α	= 0.85	Mt	2.7
Ru	0.8			Ru	0.8
Cp	0.3			Cp	0.3

Furthermore some light, fine-grained, schistose rocks are present, formed by a fine *quartz-feldspar* aggregate with a uniform grain in which patches can be distinguished which have been formed from the union of a few better developed particles of *plagioclase* and enclosing poikiloblastic flakes of muscovite and small crystals of epidote. Other poikiloblastic flakes of light mica are present in the fine aggregate (54 PZ-72).

In *the outer zones* of the marginal belt the surrounding rocks are intersected, sometimes concordantly, sometimes discordantly, by veins or pseudo-dykes. These veins, of variable thickness, are sometimes light, with fine grain and aplitic appearance, and sometimes a little greyer in colour, and porphyric because of the presence of large plagioclasic particles which vary in number and in dimension from dyke to dyke and from one point of the same dyke to another.

I was able to observe under the microscope only one sample of a porphyritic pseudo-dyke, taken near Dasu (54 PZ-16). It has a *fine groundmass* similar to that one found in the enclosed rocks in this same zone (i. e., to the biotite-epidote gneisses enclosed in the plagioclase gneisses described above (54 PZ-17 a). Some *plagioclasic porphyroblasts*, perfectly analogous to those that characterize the rocks of the plagioclase gneissic mass, have developed in this fine aggregate (Plate 11, fig. 2 and 3). This sample, which has been analysed (Table 14),

TABLE 14

Biotite-epidote gneiss with plagioclasic porphyroblasts; *to the west of Dasu* (54 PZ-16).

CHEMICAL COMPOSITION

(Analyst: C. Viterbo)

SiO_2	69.77%	MgO	1.44
TiO_2	0.48	CaO	3.67
P_2O_5	0.14	Na_2O	4.57
Al_2O_3	15.43	K_2O	1.23
Fe_2O_3	0.59	H_2O+	1.02
FeO	1.43	H_2O-	0.09
MnO	0.04		
			99.90

NIGGLI'S values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Biotite-epidote gneiss with plagioclasic porphyroblasts	297.3	38.8	22.3	16.7	22.2	0.15	0.68	0.75
Normal granodioritic type	280	39	22	17	22	0.45	0.4	

Basis				*Molecular Norm*	
Q	52.5	Q	= 52.5	Q	24.2
Kp	4.3	L	= 39.7	Or	7.1
Ne	24.7	M	= 7.3	Ab	41.2
Cal	10.7	M′	= 7.8	An	17.8
Sp	0.1	π	= 0.26	En	6.5
Fs	0.6	μ	= 0.68	Hy	1.9
Fo	4.9	γ	= —	Cord	0.2
Fa	1.7	α	= 10.14	Mt	0.6
Ru	0.4			Ru	0.4
Cp	0.1			Cp	0.1

does not appear to be similar to any one of the known "magmatic types" as seen in the plagioclase gneisses of the mass. In comparison with the plagioclase gneisses this rock shows a low content of Na_2O, but the value of the coefficient *k* remains low.

I think also that the lighter veins, of aplitic appearance, do not differ substantially from the pseudo-dyke just described, because one of these, found at a certain distance from this zone, south of Dasu, but similar to those observed here, does not show significant differences in the microscopic analysis.

It appears that rocks belonging to the surrounding formations are enclosed not only in the agmatitic belt but also in the *inner parts* of the mass, in the form of developed pieces or in bands of remarkable thickness. Inclusions of rocks of this type have been identified in the central-northern part of the mass; at the 3,700-3,800 metres (12,100-12,500 ft) level I could distinguish large schistose bands in which bands of *greenish rocks* (similar to some *biotite-epidote gneisses* of the surrounding formation) alternated with bands of light compact fine-grained rocks. I do not know if these bands, elongated roughly NNW-SSE, are indeed isolated inside the granitoid gneissic mass, or if they are instead the end of a long band that cuts deeply for a long distance into the granitoid rocks, yet remaining in contact with the surrounding rocks.

The *light rocks* appearing in these enclosed bands have been formed by an aggregate of small particles of *sodic plagioclase*, of *quartz* and, to a lesser extent, of micas and epidotes. Only some of the patches have been formed by the amalgamation of several rather larger plagioclasic particles.

The muscovite is often found among the micas, either in thin flakes distributed in the rock without any particular orientation, or in larger poikiloblastic crystals, like those observed in the fine-grained gneisses of the surrounding formation.

CONCLUSIONS

CHEMICAL VALUES

In Table 15 are shown the data obtained from the chemical analysis made of some rocks gathered in the zone under study: a) on three samples of *plagioclase gneisses* collected in different parts of the sialic mass occurring in the zone of the Skoyo-Turmik valley. These represent the more common types of that mass (samples 1, 2, 3); b) on a light *dyke*, of porphyritic aspect (sample 4), which intersects the surrounding rocks in the outer part of the marginal belt; c) on a *fine-grained biotite-epidote gneiss* (sample 5) (corresponding to the commonest rocks of the surrounding formation) taken from a patch enclosed in the plagioclase gneisses.

The data corresponding to the sample 1, 2 and 3 show clearly the substantial

TABLE 15

THE SKOYO-TURMIK MASS OF PLAGIOCLASE GNEISSES

Analysed rocks

Locality	Petrographic classification	Chemical classification according to Niggli's magmatic types
1. – The Indus valley, to the west of Dasu; south-eastern portion of the mass. (This rock encloses pieces of the surrounding rocks).	Plagioclase gneiss with biotite and epidote (the most common facies) (54 PZ-17).	—
2. – The Indus valley, western portion of the mass; at a height of 3.900 m (12.800 ft).	Plagioclase gneiss with biotite, epidote and amphibole (54 PZ-75).	—
3. – The Lower Turmik valley, close to the north-eastern contact.	Plagioclase gneiss with biotite and epidote; with no schistosity (54 PZ-92).	—
4. – The mouth of the Turmik valley; dyke at the periphery of the mass, within the basic schists.	Biotite-epidote gneiss with plagioclasic porphyroblasts (54 PZ-16).	—
5. – The Indus valley, to the west of Dasu, (this rock is enclosed in the plagioclase gneisses).	Fine-grained biotite-epidote gneiss (54 PZ-17a).	*Normal dioritic type.*

CHEMICAL COMPOSITION

	1 Analyst : (C. Viterbo)	2 Analyst : (C. Viterbo)	3 Analyst : (C. Viterbo)	4 Analyst : (C. Viterbo)	5 Analyst : (C. Viterbo)
SiO_2	68.39%	65.65%	69.19%	69.77%	57.74%
TiO_2	0.52	0.47	0.21	0.48	1.12
P_2O_5	0.11	0.19	0.36	0.14	0.31
Al_2O_3	13.17	15.46	14.24	15.43	17.25
Fe_2O_3	1.02	1.18	1.25	0.59	2.62
FeO	1.72	1.72	0.87	1.43	3.83
MnO	0.05	0.04	0.03	0.04	0.09
MgO	1.49	1.99	0.44	1.44	3.00
CaO	4.03	4.61	3.25	3.67	5.53
Na_2O	6.56	6.70	6.06	4.57	4.11
K_2O	1.81	1.31	2.12	1.23	2.63
H_2O+	1.08	0.82	1.60	1.02	1.53
H_2O-	0.08	0.11	0.06	0.09	0.09
	100.03	100.25	99.68	99.90	99.85

TABLE 15 - (Continued)

	NIGGLI's values						
Analysed rocks	*si*	*al*	*fm*	*c*	*alk*	*k*	*mg*
1. Plagioclase gneiss	267.9	30.4	23.3	16.9	29.4	0.15	0.62
2. Plagioclase gneiss	245.9	34.1	19.9	18.5	27.5	0.11	0.56
3. Plagioclase gneiss	322.5	39.1	10.9	16.3	33.7	0.19	0.28
4. Biotite-epidote gneiss with plagioclasic porphyroblasts	297.3	38.8	22.3	16.7	22.2	0.13	0.68
5. Fine-grained biotite-epidote gneiss	165.9	29.2	36.6	17.0	17.2	0.33	0.58
NIGGLI's *magmatic types*							
Granitic magmas:							
Adamellitic type	300	37.5	22.5	13.5	26.5	0.45	0.3
Granodioritic magmas:							
Normal granodioritic type	280	39	22	17	22	0.45	0.4
Trondhjemitic magmas:							
Normal trondhjemitic type	370	42	12	11	35	0.25	0.3
Dioritic magmas:							
Normal dioritic type	155	30	35	21	14	0.3	0.5

analogies existing among the analyzed plagioclase gneisses in accordance with the results of the observations in the field and under the microscope. The abundance of feldspar in the rocks under examination, represented exclusively by a plagioclase about 20°/₀ An, is the reason for the high content of Na_2O, oscillating between 6.0°/₀ and 6.7°/₀. The richness in soda as against potash is without doubt the most typical characteristic of the rocks of the granitoid mass, as shown by the value of the coefficient *k* of the Niggli's values varying between 0.19 and 0.11. This is so low that one cannot classify these rocks among the known magmatic types. Only one of the three rocks analysed, that is the one without schistosity (sample 3), and poorer in femic minerals, because of its slightly higher content in K_2O ($k = 0.19$) is similar to the normal trondhjemitic type of the Niggli classification ($k = 0.25$), but it differs from this in respect of the high value of *c* (16.3 against 11).

The chemical data referring to the dyke with plagioclasic porphyroblasts (sample 4) are very similar to those given for the plagioclase gneisses, with the exception of the Na_2O content, which is lower (4.57°/₀ as against the 6°/₀ or little more of the plagioclasic gneissic rocks). Also the comparison of the Niggli's values deduced from the weight percentages, indicate that the only important difference concerns the value of *alk*, decidedly lower than that of the gneisses of the granitoid mass, while the value of *k* remains consistently very low (0.15). Also this rock does not appear to be similar to the "magmatic types" given by NIGGLI.

The fine-grained biotite-epidote gneisses enclosed in the plagioclase gneisses in the inner part of the marginal belt have a composition similar to that indicated by NIGGLI for the dioritic magmas, and corresponding almost exactly to the normal dioritic type.

The values of the five analyzed rocks as seen in a diagram *k* — *mg* (fig. 8) shows clearly the *decidedly sodic character* of the plagioclase gneisses (both the rocks of the granitoid gneissic mass (samples 1, 2, 3) and the dyke (sample 4)).

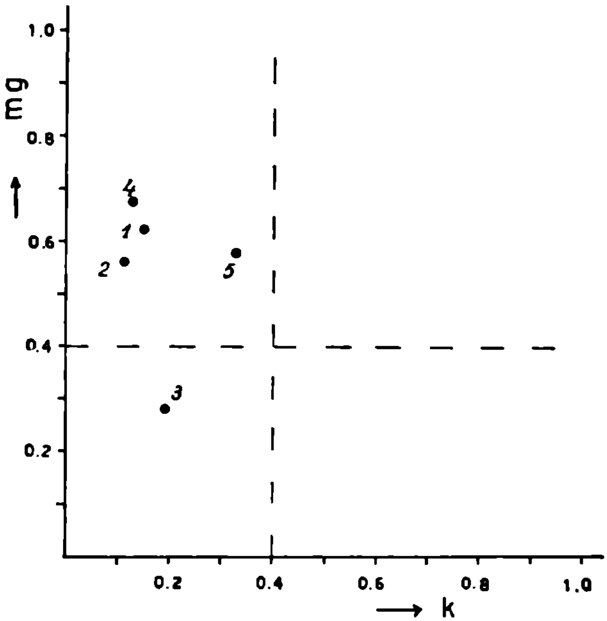

Fig. 7 - Representative points of the analyzed rocks plotted on the *k-mg* diagram.

The representative points of these sialic rocks, (*si* 250-320), fall in an area of the diagram belonging to magmatic types which are decidedly femic.

Neither in this case, however, the rocks in discussion show the correspondent value with that of the common magmatic one. Point 5 which indicates a fine-grained epidote-biotite gneiss of the host rock formation, falls in the sector of dioritic type rocks.

In the triangular diagram k - π (where $\pi = Cal/Kp + Ne + Cal$) the points representing the plagioclase gneisses are grouped near the Na corner thus showing their distinctly sodic character as well as their poverty of Ca combined with Al. The position of point 5 indicates that the fine-grained biotite-epidote schist has a higher *k* and Ca (Cal) content than the plagioclase gneisses; point 4 has an intermediate position, having the value of *k* equal to those of the plagioclase gneisses and the value of Cal equal to that of the fine-grained schists of dioritic composition.

PETROGENESIS

As I have mentioned several times previously, in the regions south of Indus river metamorphic formations of volcanic-sedimentary origin have been specified and described. In the Skoyo-Turmik zone rocks of similar origin surround the mass of plagioclase gneisses. But there is no evidence of the presence

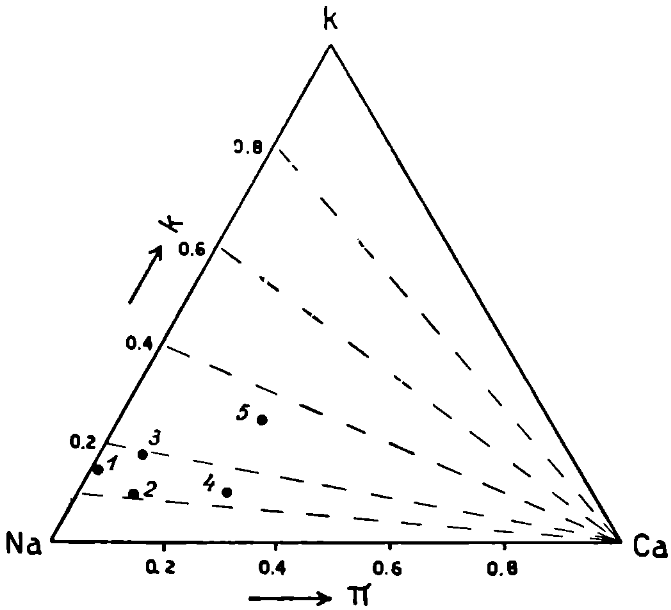

Fig. 8 - Representative points of the analyzed rocks plotted on the k - π diagram.

of granitoid masses analogous with that mentioned above and therefore important information is missing to complete the observations done by me to make clear the petrogenetical interpretations.

Summing up briefly what has been expounded in detail in the preceding chapters, the Skoyo-Turmik gneissic mass seems to be formed inside basic schistose rocks of volcanic origin; the boundaries of this mass are not sharp but it is separated from the surrounding rocks by an agmatitic belt of variable thickness. The rocks that form this mass are characterized by the presence of large plagioclase porphyroblasts with no definite orientation and having a seeming schistosity concordant with that of the surrounding rocks.

Under the microscope these rocks show a crystalloblastic texture and the oligoclase porphyroblasts are seen to possess considerable dimensions, a rather uniform composition and a typical fagocitarious appearance determined by the constant presence in them of inclusions of muscovite, epidote, quartz, biotite and amphibole (Plates 8, 9).

In the following pages I will try to explain from the petrogenetic point of view all the chemical, petrographical and textural features found during the researches.

Concerning this subject I recall that in some preliminary notes (B. Zanettin, 1956, 1957; C. Viterbo & B. Zanettin, 1959) I have briefly mentioned the possibility that the Skoyo-Turmik plagioclasic gneissic mass with porphyroblastic texture could have been formed by a process of metasomatic type. The knowledge acquired of the geological situation of the surrounding regions and a close analysis of petrographic characteristics provide favourable arguments, or at least arguments which do not oppose the hypothesis of a genesis by metasomatism.

The mechanism of crystallization of the plagioclasic porphyroblasts.

The connection between the different characteristic petrographic features of these rocks and the eventual solution of the genetic problem devolve on the possibility of determining with sufficient exactness the mechanism of formation of the feldspathic porphyroblasts which, as it is known, form about one half of the rocks by volume.

Fortunately the rocks under examination enable very significant observations to be made from this point of view. It has been seen in fact that in some facies the small plagioclases, which together with grains of quartz, muscovite and epidote form a characteristic mineralogical aggregate of large light patches, have an orientation which varies little between each particle and the contiguous particles. Thus the limit between grains is nearly indistinguishable, and in some cases they seem to form a large single porphyroblast with irregular extinction enclosing the grains of quartz, the muscovite and the epidote (Plate 10, fig. 4).

Near the granoblastic patches from which these doubtful, not clearly marked porphyroblasts are growing, the usual porphyroblasts of plagioclase which are rich in inclusions are present (Plate 9, fig. 4; Plate 10, fig. 4).

It can be said simply, that the *formation of the plagioclase porphyroblasts occurs by progressive iso-orientation of the small plagioclase granoblasts of the matrix.* This process has its origin in one particular point or points of a feldspathic-quartzose portion of the fine-grained mineralogical aggregate and then proceeds towards the outer parts involving an always increasing number of small plagioclasic grains. When, as it often happens, the process stops before all the small plagioclases of a portion assume the same orientation, the porphyroblast, or the porphyroblasts formed in this way seem to penetrate between the minerals of the fine-grained aggregate pushing into it in an irregular way. This fact explains the absence of any defined limits in the large plagioclases.

When the now described process of homogenization has origin from many distinct points of the granoblastic matrix, then several minor porphyroblasts grow in it and, at the end of the process, fuse together forming porphyroblastic patches with differently oriented portions.

The formation "in situ" of a large plagioclase, at the expense of the small plagioclases constituting a granoblastic aggregate in which is found a variable quantity of quartz, epidote, biotite, muscovite and, sometimes amphibole, leads, logically, to the enclosing of these minerals (Plate 8, figs. 1, 2, 3). Indeed the many inclusions which represent one of the more noticeable and constant characteristics of the feldspathic porphyroblasts of the rocks under study (with the exception of the orientated sericitic and epidotic microlites of which more will be said later) are considered to be pre-existing minerals now enclosed. The hypothesis is supported by the fact that *in the plagioclasic poikiloblasts the nature of the inclusions is related to the mineralogical composition of the rock.* Thus, for example, the amphibolic inclusions are found only in the amphibolic facies, and are more frequent in rocks in which amphibole is abundant.

It is also interesting to note how these minerals are gradually transformed and fagocitated as they are enclosed (Plate 9, figs. 1, 2, 3). This phenomenon is evident both in the quartz and femic inclusions. It has, in fact, been stated that the latter, and especially biotite and hornblende, are more frequent at the edges of porphyroblasts than in the central parts, and that, in any case, the larger inclusions are always confined to the edges. Their transformation which can be followed, step by step, mainly by the variations in optic characteristics (diminution of pleochroism, variations of birefringence), results in the appearance of new crystalline phases (light micas from biotites, epidote from hornblende) probably representing intermediate stages of replacement by the plagioclase.

Still more evident is the replacement of quartz by plagioclase, especially when the enclosed grains of quartz have zig-zag limits corresponding to those edges which intersect the composition planes of the plagioclasic twins. Because the plagioclase penetrates more deeply into the quartz along these planes, it is easy to deduce that the speed (rate) of transformation of quartz to plagioclase reaches its maximum along these composition planes (Plate 10, figs. 2 and 3).

At the same time as the formation of the plagioclasic porphyroblasts the other mineralogical components (epidote, biotite, etc.), also recrystallize, grow and tend to combine into essentially femic patches.

THE GENESIS OF THE PLAGIOCLASE GNEISSES.

The petrographical motif which allows us to establish the conditions under which the plagioclase gneisses formed is given by the tendency to the porphyroblastesis of the plagioclase and by the outstanding recrystallization of the other components.

Because such a tendency to the porphyroblastesis is not found either in the basic schists, (the host rocks) or in the clods of basic schists which in the agmatitic belt are cemented by the plagioclase gneisses, we come to the conclusion that the origin of the porphyroblastesis was subsequent to the main stages of the regional metamorphism; it is unlikely that the regional metamorphism has acted on the plagioclase gneisses with higher intensity than on the surrounding femic rocks.

There is therefore every reason to believe that the formation of the porphyroblasts of the plagioclase gneisses must be connected with particular factors which have acted locally, (that is in the area where the plagioclase gneisses outcrop) and which have been able to impart an exceptionally sodic chemical composition to the rocks subjected to their action.

The introduction of solutions rich in soda and silica into meso-iposilicic metamorphic rocks analogous to the rocks of the surrounding formation would be able to cause either a local rise of temperature, thus furthering the general recrystallization of the rock, or metasomatic reactions, which being able to take place at relatively low temperatures, could cause at the same time the development of the plagioclasic porphyroblasts and a fairly substantial modification of the chemical composition of the rocks affected by the process.

I think that the genesis of the plagioclase gneisses of the Skoyo-Turmik mass is to be attributed precisely to a process of this type, helped by some of the considerations briefly outlined below:

(a) *The nature of the minerals of the plagioclase gneisses is the same as that met in the surrounding rocks*, the difference between them being due only to the different quantitative ratio between the minerals and to the different texture. In the proximity of the fine-grained biotite-epidote gneisses of dioritic composition the plagioclase gneisses consist mainly of biotite and epidote; near the amphibolites (north-western part of the granitoid mass) the main femic component of the plagioclase gneisses is an amphibole;

(b) *The fine-grained feldspathic-quartzose aggregate present in small patches in the plagioclase gneisses is similar to that of fine-grained basic surrounding gneisses.* This fact is particularly evident in some porphyroblastic facies of the marginal belt. These facies have a dyke form. In these the fine-grained schistose aggregate of the matrix is so similar to the surrounding basic rocks that the two types can be distinguished only by the presence, in one of them, of large plagioclasic crystals. These rocks, rather rare compared with the more common plagioclase gneisses, can be considered as transitional between these and the surrounding rocks (Plate 11, figs. 1, 4). Chemical analysis only partially confirms this transitional character which is so evident under the microscope, but it is not possible to draw definite conclusions in one or the other way on the basis of chemical data from rock samples taken from places rather far apart, and which could therefore show remarkable original differences of composition;

(c) *The existence of sandstone-like beds inside the mass of plagioclase gneisses.* These light, fine-grained rocks, interbedded with the usual fine-grained basic gneisses, probably represent rocks which have almost completely escaped feldspathization, thanks to their compactness;

(d) *The chemical composition of the plagioclase gneisses.* Of particular importance is the exceptionally low ratio of k (from 0,11 to 0,19) which does not correspond to that of persilicic igneous rocks, but which can result from the introduction of comparatively small quantities of soda into rocks with a low potash content, like the surrounding basic rocks.

Furthermore, it is worth noting the fact that the value of c in our rocks, which is exceptionally high for persilicic rocks, is nearly the same as that met in the surrounding gneisses of dioritic composition (amphibolites) (Table 15). This would seem to indicate that the lime (calcium) in the pre-existing rocks was not expelled during the metasomatic process of feldspathization.

It might be thought that, since the formation of the plagioclasic porphyroblasts occurred in an environment very rich in lime (epidote) and, probably, at temperatures higher than those existing in the surrounding area, the composition of the porphyroblasts ought to be more calcic than that of the small plagioclases of the surrounding rocks. Except in certain cases, however, it does not seem that differences of more than 5°/₀ An exist between them. Such a similarity of composition could, of course, have been caused by a successive segregation of epidote in the porphyroblasts of the plagioclase gneisses as a result of late weak epimetamorphic manifestations. Evidence of this process is afforded by the very small crystal of epidote which, together with many sericitic flakes lie in various directions, corresponding to composition planes of twinning and to cleavage of the host plagioclase (see C. ANDREATTA, 1933, 1934; A. BIANCHI, 1934).

Our knowledge of the metasomatic process is completed by the absence of any definite orientation of the lamellar recrystallized minerals of the granitoid rocks. This fact establishes that the process of granitization occurred under static conditions. The seeming schistosity shown by these rocks in the field is due to a certain orientated disposition shown by the femic patches and can probably be considered as a relic of the pre-existing schistose texture. This seems to be confirmed by the fact that in the outer less intensely feldspathized facies the pre-existing schistosity is still clearly maintained.

SUMMARY OF THE GENETIC PROCESSES.

Summing up what has been developed above it can be thought possible that the plagioclasic gneisses which form the Skoyo-Turmik mass derive from the following successive processes:

(1) Regional metamorphism corresponding to the higher mesozone of the meso-and iposilicic volcanic terrains (and of the sedimentary rocks interbedded with them) with the formation of amphibolites, amphibole-epidote and biotite-epidote gneisses etc.

(2) Introductions of silica and soda at temperatures able to cause the recrystallization of the pre-existing minerals and to promote metasomatic reactions, thus forming plagioclasic porphyroblasts and removing a variable quantity of iron and magnesium (1). In this way the rock, having a typical metamorphic texture, takes on the appearance of a granitoid rock rich in large

(1) There are no elements apt to establish the prevailing physical conditions and the mechanism of introduction of silica and of soda and removal of iron and magnesium.

plagioclasic particles and whose chemical composition approaches that of persilicic rocks although possessing a higher ratio Na : K and a higher content of Ca.

(3) Weak post-crystalline metamorphic action which caused a decrease in the An content of the neo-formed plagioclases by the splitting out of epidote and sericite which assume an orientated disposition in certain crystallographic planes of the plagioclase itself.

Also in this case, as in other similar cases, it is not easy to establish the precise origin of the introduced materials since field investigations do not give any exact indications on this subject. In the absence of any objective proof my own opinion is that the substances which have caused the above mentioned metasomatic process could have been of magmatic origin because in the neighbouring region there are many extensive magmatic masses which very probably are coeval with the Skoyo-Turmik mass (see general conclusions). Among these I would mention the mass of the Shigar valley, the extensive masses of hornblende granite and diorite occurring south of the zone mapped by me (G. DAINELLI, 1934; D. N. WADIA, 1937).

A certain connection, not yet complete, seems to exist between the plagioclase gneisses of Skoyo-Turmik and the plutonic mass of the Shigar valley. In fact some of the many light veins or dykes, aplitic in appearance, which cut in all directions the schistose basic rocks occurring on the left side of the Turmik valley, south of the village of Smurdo, (see page 88) show petrographic features not very different from those met in the dykes of the marginal belt of the mass under study. These dykes point towards a zone which is very near to the outcrops of the plutonic rocks of the Shigar valley.

IV

THE TURMIK VALLEY ZONE

This zone contains the whole of the hydrographic basin of the *Turmik valley*, with the exclusion of that part on the right side where the plagioclase gneisses which form the sialic Skoyo-Turmik mass occur.

In this chapter descriptions are given also of the rocks occurring for some ten kilometres on the right side of that part of the *Indus valley* south of the confluence with the Turmik valley, between this confluence and the village of Gurbidas. Separate details will also be given about some rocky formations which occur south of this village, but still in the Indus valley.

The Turmik valley has its source at the Stak-la (4,601 m; 15,491 ft) (that is on the saddle which leads to the basin of the Stak valley) and runs, with a NW-SE direction and nearly uniform slope, towards the Indus river reaching it just where this river forms an elbow which changes the direction from south-north to east-west. Our valley is separated from the trunk of the Indus river west of the confluence (that is to say from the Skoyo-Turmik zone and from the Twar zone) by a high ridge whose main direction is west-north-west. This ridge rises with a north-west or north-norht-west direction towards the Stak-la, and forms high walls which divide the Turmik valley from the upper basin of the Askore valley. On the other side, the Turmik valley is separated from the basin of the Basha valley by a dissected ridge, which continues south-south-east for some scores of kilometres reaching to above Skardu and forming the divide between the Indus and Shigar valleys.

The morphology is somewhat different on either side of the Turmik valley. On the right side (or, more exactly, on the right side of the middle and lower branch) it is relatively gentle. However, it is steeper and characterized by many canyon-like incisions on the left side of the middle and upper branch (and on the right side of the upper branch). This is a result of the different lithological constitution of the two sides.

All the rocks occurring in the zone now indicated belong to a single geological formation (volcanic-sedimentary series of Cretaceous age), which also

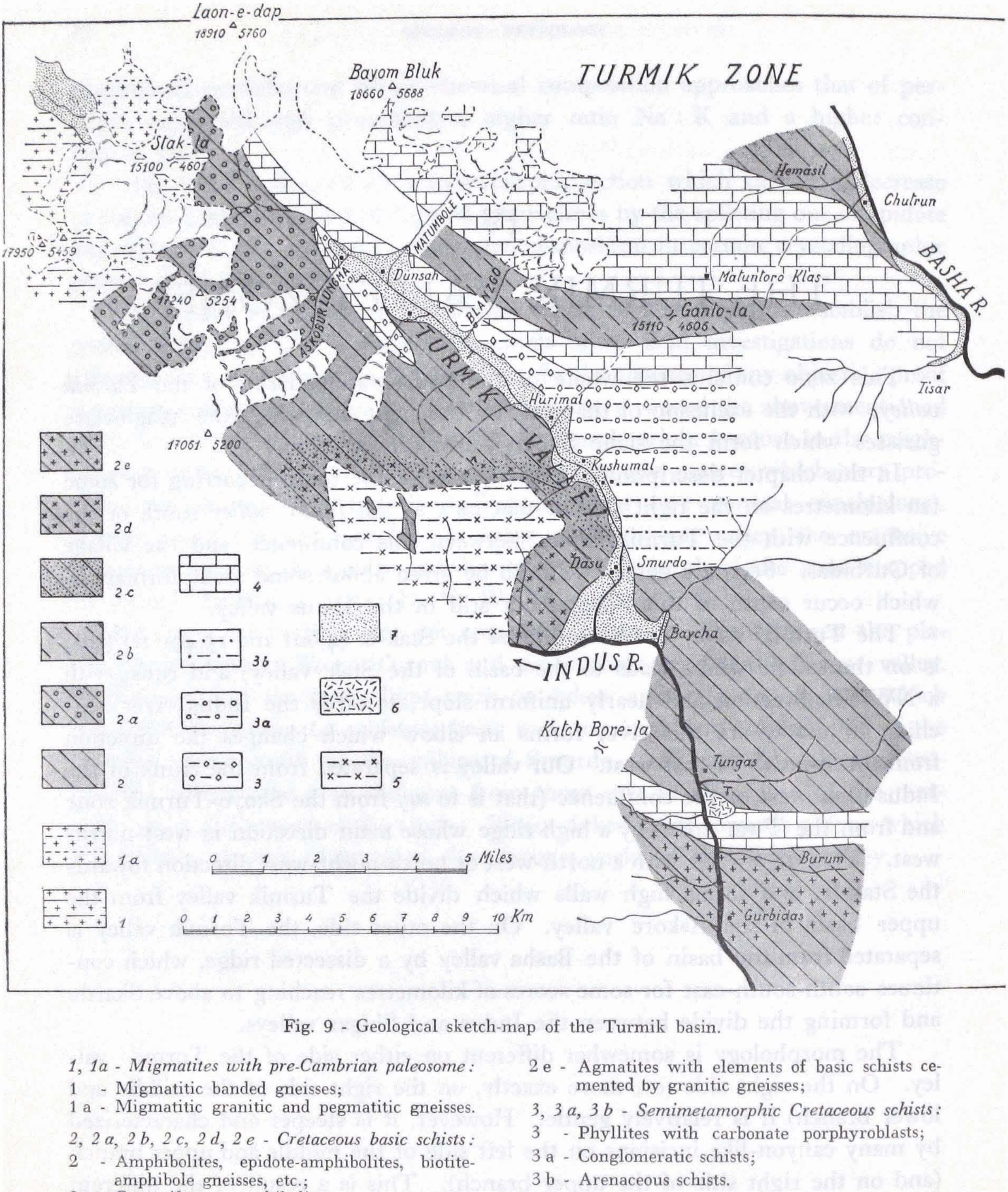

Fig. 9 - Geological sketch-map of the Turmik basin.

1, 1a - Migmatites with pre-Cambrian paleosome:

1 - Migmatitic banded gneisses;

1 a - Migmatitic granitic and pegmatitic gneisses.

2, 2 a, 2 b, 2 c, 2 d, 2 e - Cretaceous basic schists:

2 - Amphibolites, epidote-amphibolites, biotite-amphibole gneisses, etc.;

2 a - Garnetiferous amphibolites;

2 b - Greenschists (epidote-chlorite schists, clorite-actinolite schists, etc.);

2 c - Basic schists with mica or amphibole porphyroblasts;

2 d - Agmatites with elements of basic schists cemented by plagioclase gneisses.

2 e - Agmatites with elements of basic schists cemented by granitic gneisses;

3, 3 a, 3 b - Semimetamorphic Cretaceous schists:

3 - Phyllites with carbonate porphyroblasts;

3 a - Conglomeratic schists;

3 b - Arenaceous schists.

4 - Limestones, marly limestones, dolomites, marbles, calc-schists, conglomeratic limestones.

5 - Plagioclase gneisses.

6 - Hypersthene diorites.

7 - Moraine, alluvium and debris.

extends into the surrounding regions, with the exception of the Stak zone, where migmatitic biotite-kyanite-garnet gneisses occur. One of these regions, the basin of the *Basha valley* which runs north-east of the Turmik valley, is almost unknown to me, and here I have made only one excursion (on the slope from Ganto-la to the village of Chutrun). The evidence that in the area over which I travelled the same rocks as observed in the Turmik valley occur induces me to outline the little information gathered directly or indirectly on them in this chapter.

As I have said in the introduction (page 1), the first geological observations were made in this zone by A. DESIO (1953); in the discussion on the following pages I have also used the geological sketch-map and the information which he has put at my disposal.

GEOLOGICAL CONDITIONS AND PETROGRAPHIC FEATURES

THE ROCKS OF THE INDUS VALLEY, ABOVE THE CONFLUENCE WITH THE TURMIK VALLEY

I covered the Indus valley between Katzarah and Gurbidas so quickly that I could form no exact idea either of the extent of the different terrains observed, or of the relations existing between them. Regarding this part of the valley, therefore, I shall limit myself to showing the petrographic characteristics of the few samples gathered by me in 1954 and by A. DESIO in 1953. I recall that south of Tungas a great variety of rocks is encountered, whilst between Tungas and Dasu (situated at the mouth of the Turmik valley) there is, on the contrary, a remarkable uniformity of terrains.

The most southerly zone of the Indus valley in which I made observations was on the left side of the valley, near the little lake of Katzarah (Forok Tso). Here the more widely spread rocks have very characteristic appearance and correspond to schists with a matrix of grey-ashy colour, in which many relatively well developed biotite flakes and some garnet are distributed with a certain regularity. These schists are often injected "lit par lit" by thin granite-like dykes, which sometimes seem to include and transform bands of schists by forming dark patches, similar to "schlieren", while the same dyke rock seems to change in appearance.

A sample (54 PZ-1) taken near the junction with a dyke is seen to consist of *labradorite-biotite-sillimanite gneiss rich in garnet*, in which the smaller part is formed with an aggregate of *fine-grained quartz* and of *labradorite-bytownite* plagioclasic individuals. The biotite is present as large flakes, very often altered at the edges into *sillimanite*, which is very abundant and represents a fundamental mineral of the rock (Plate 12, fig. 1).

A facies similar to this, but poorer in sillimanite, has been observed by A. Desio (53 PD-2) near the village of Tsordas, on the right side of the Indus river.

Rocks of this type (or, rather, their metamorphic equivalents of lower grade) also occur, in the neighbourhood of the Forok Tso, and near the great cement bridge which crosses the Indus river near Ponedas. They have a NE-SW strike and plunge NW with a steep dip (1).

I can say very little about the rocks forming the right side of the Indus river from Ponedas to Basha (this last village is situated on the left bank of the Indus river) except that they are for the most part subvertical schistose rocks with a SSE-NNW direction, crossed by many *aplitic* and *pegmatitic dykes rich in garnet* (54 PZ-2) and enclosing some small masses of massive amphibolic rocks not very well defined (noritic diorites?). Near the elbow of the Indus river, opposite the village of Basha *tonalitic or dioritic* gneisses (54-PZ 3) are predominant. These have a structure which reminds that of the rocks of Twar (see below). There are also *amphibole* or *amphibole-biotite fine-grained gneisses* (54 PZ-3 a) intimately mingled with them.

Also in this zone occur some *augite-amphibole-biotite gabbrodiorites* (54 PZ-4) (Plate 12, fig. 2) and some *hypersthene diorites* (53 PD-4), which should undoubtedly be considered as similar to the rocks of the noritic type which form a conspicuous intrusive mass in the Twar zone.

A peculiar rock was gathered by A. Desio (53 PD-3) along this part of the valley. Both macroscopically and microscopically it seems to combine the characteristics of the intrusive rocks of the 54P Z-3 and 54 PZ-4 types and of the biotitic-sillimanitic contact schists of the 54 PZ-1 and 53 PD-2 type. Nearly half of this rock is formed of *quartz*, *biotite* and well twinned *andesine-labradorite plagioclase*, similar to that of the pyroxenic diorites. The other half is formed with *labradorite* 50-60°/₀ An particles of similar dimensions to the others, but *poikiloblastic* because of the inclusion of many quartz grains and, in smaller quantities, biotite, apatite, iron ore and calcite. Besides these, some aggre-

(1) Rocks similar to these occur in the Shigar valley.

gates of *small calcic plagioclase*, similar to those of the biotite-sillimanite gneisses are present in this area.

These basic rocks, including portions of fine-grained amphibolic gneisses, or themselves a little schistose, continue to about the height of Foldo. Between Foldo and Gurdibas, besides the usual fine-grained amphibolic-biotitic gneisses (53 PD-6) interbedded with a smaller quantity of gneissic biotitic micaschists (53 PD-5), lighter rocks with the appearance of *granodiorites* and *tonalites* occur.

Beyond Gurbidas my observations were more intensive and I am therefore able to give more exact and detailed information of the rock formations occurring between this village and the mouth of the Turmik valley.

Femic schistose rocks with fine grain occur again near Gurbidas. These amphibolic-biotitic rocks are so rich in plagioclase as to merit the name of *amphibolitic gneisses* rather than amphibolites (54 PZ-5 and 7). They are very similar to the fine-grained basic schists occurring both in the Twar zone and in the Turmik valley, but they differ in some cases in an obvious zoning of the plagioclase (1) (this was never seen in similar rocks in the other zones mentioned).

A chemical analysis was made on the sample 54-PZ 7, taken from a patch of amphibolite enclosed in the granitic rock which will be described below. This shows (Table 16) how the rock possesses an intermediate composition between that of the *gabbroic magmas* and that of the *gabbrodioritic magmas*, showing close analogies with the *normal gabbrodioritic type*.

A little further on light *granitic* rocks of very variable aspect occur. These are patched by long *streaks or bands* formed nearly exclusively of *biotite*. When these biotitic patches are very frequent and regularly distributed the rock assumes the characteristic "leopard skin" appearance so often shown by intrusive rocks near the contact surfaces. Moreover *portions of amphibolites* of the type indicated above (with zoned plagioclase) are often enclosed in these rocks. Then the enclosing rock often takes on the appearance of a microdiorite, especially where the contacts with the amphibolites are unweaved. The strike of the enclosed amphibolites is always perfectly concordant (NW-SE) with that of similar rocks occurring to the south and north. Many concordant *aplitic veins* cross these amphibolic dark rocks, whilst other larger *aplitic and pegmatitic dykes* discordantly intersect both enclosed and enclosing rocks.

(1) The determinations made in the albite and albite-Carlsbad twins give the following results: core = 34, 35, 37, 40% An; marginal portions = 24, 25, 29, 30% An.
At the outer part of the crystals a composition of 20% An has also been measured.

TABLE 16

Amphibolite; *near Gurbidas* (54 PZ-7).

CHEMICAL COMPOSITION

(Analyst: B. Zanettin)

SiO_2	51.73%	MgO	8.60
TiO_2	0.48	CaO	8.73
P_2O_5	0.09	Na_2O	4.04
Al_2O_3	16.67	K_2O	1.05
Fe_2O_3	1.62	H_2O+	1.76
FeO	4.76	H_2O-	0.02
MnO	0.10		
			99.65

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Amphibolite from Gurbidas	123.6	23.5	43.2	22.3	11.0	0.15	0.71	0.75
Normal gabbrodioritic type	130	23	44	22.5	10.5	0.2	0.5	

Basis				*Molecular Norm*	
Q	29.0	Q	= 29.0	Or	6.2
Kp	3.7	L	= 39.9	Ab	36.2
Ne	21.7	M	= 30.6	An	24.2
Cal	14.5	M'	= 31.1	Wo	7.5
Cs	5.6	π	= 0.36	En	5.0
Fs	1.7	μ	= 0.58	Fo	13.9
Fo	17.7	γ	= 0.18	Fa	4.8
Fa	5.6	α	= 0.24	Mt	1.7
Ru	0.3			Ru	0.3
Cp	0.2			Cp	0.2

One of the more common facies of this granitic type of rock corresponds to a *leucogranite* (54 PZ-6; 53 PD-9), rich in *microcline* and *microclineperthite* often enclosing large grains of quartz and, more rarely, biotite and muscovite. Quartz is also abundant, while *oligoclase* of variable composition (25-35% An) is scarcer. *Biotite* and *muscovite* are present with poikiloblastic flakes of remarkable development. *Ferriferous epidote* is common amongst the less important minerals. In some cases rocks of this type take on a certain schistose texture because of the orientated disposition of the biotite flakes.

In the locality of Burum, where a steep valley comes down to the Indus river, the complicated mixed formation just described is succeeded by *crystalline limestones*, whose outcrops can be followed for a long distance on both sides of the Indus river. These limestones, subdivided into two great parallel bands separated by a bed of amphibolites, have a total thickness of 400-500 m (1,300-1,600 ft).

Both bands are formed at some point of white *marbles* (54 PZ-8) with thin beds of calciphyres and *amphibolites* (54 PZ-10), in which plagioclases, whose composition varies from the centre outwards, are found. The dark schistose band, which is interposed between the calcareous bands, has a thickness of about 60 metres and is formed by the usual *fine-grained acicular amphibole-biotite gneisses* (54 PZ-9).

This calcareous-amphibolitic mass continues in an approximately east-west direction without interruption, plunging to the south with a very steep dip, on the left side of the Indus valley, and very probably passing by the Katch Bore-la. However, it suddenly changes direction east of Rondu turning north-south so as to intersect the Indus valley at right angles near the village of Mulakor. Here it comes in contact with the basic rocks of the Twar mass causing the formation of coarse-grained femic rocks (see page 37, 38, 43).

A similar phenomenon also occurs near Tungas, where the calcareous rocks come in contact with hypersthenic diorite (54 PZ-11), of the same type as the dioritic-noritic rocks of Twar, thus determining the development of an exceptionally coarse-grained *amphibolic band.*

This hypersthenic diorite, found immediately north of the beds of marble, forms a particular facies of the intrusive noritic rocks which were frequently seen inside the amphibolite formation occurring all along the right side of the Indus river, from Tsari to the Askore valley. The most strikingly characteristic petrographic feature is the *biotite*, which appears as great crystalloblastic flakes rich in inclusions of small pyroxene crystals bordered by amphibole, so as to prevent the direct contact between biotite and pyroxene (Plate 12, fig. 3). Furthermore the *amphibole*, sometimes very abundant in these types of rocks, is very scarce and limited to the edges of the *pyroxene* (Plate 12, fig. 2), whilst potash-feldspar is totally absent. The extreme richness of thin acicular minerals enclosed in the plagioclase (1) is also remarkable. These follow well defined lines (Plate 12, fig. 4).

(1) The determinations made in albite and albite-Carlsbad twins indicate composition ranging from 48 % to 54 % An.

Except for this small outcrop of intrusive femic rocks, all the right side of the Indus valley between the calcareous beds of Tungas and the mouth of the Turmik valley is formed of schistose amphibolic rocks similar to those found south of Burum (54 PZ-5 and 7) and to those occurring on the right side of the Turmik valley and north of Mulakor, in the Twar zone. This petrographic similarity confirms the stratigraphic relationship between the rocks occurring in these different zones, a relationship easily deduced in the field by the trend of the calcareous bands. They form repeated alternations of *amphibole*, *amphibole-biotite* and *biotite-amphibole gneisses* with *epidote amphibolites* (54 PZ-12 and 13; 53 PD-12, 13 and 14). In other words these are all fairly similar rocks, which could be combined under the generic term of *amphibolites*. The darker rocks, richer in amphibole, seem, in general, to be scarcer than the others, but are nevertheless distributed with a certain regularity.

The whole of the amphibolitic formation is intersected by light concordant veins and dykes, and these become more frequent from south to north. Between Baycha and Dasu these dykes suddenly become very thick and frequent and also discordant. Various type of dyke can sometimes be distinguished in the field. Some show a certain individuality, and are clearly defined in the surrounding rocks. These have a more or less regular trend and thickness whereas some others do not show well defined limits and these often increase, straighten or split up into many small concordant veins separated by thin schistose amphibolic streaks and rapidly change in composition, sometimes being poor and sometimes rich in femic minerals.

The first type often have an *aplitic* or *granitic-aplitic* appearance due to the fine grain of the *quartzose-plagioclasic* ground (albite-oligoclase 12-18°/₀ An), and a certain schistose texture due to the orientated disposition usually shown by the more or less abundant *micaceous* or *epidotic* crystals inside the granoblastic aggregate. The texture can be uniform (53 PD-15), or porphyroblastic (54 PZ-15) due to the presence of large feldspathic patches, sometimes formed of a single *plagioclasic poikiloblast* (albite-oligoclase about 15°/₀ An), sometimes with the combination of many plagioclasic particles of remarkable dimensions. In either case these porphyroblasts enclose micas and epidotes lacking defined orientation (1).

(1) The porphyroblastic gneissic-aplitic dykes of the type now described show a certain analogy with the dykes observed on the margins of the plagioclase gneissic mass occurring between Skoyo and the Turmik valley (54 PZ-16) (see pag. 70).

A typical sample (54 PZ-14) of the most variable type of dyke shows an alternation of feldspathic and amphibolic bands. Under the microscope it can be established that the light quartzose-plagioclasic (albite-oligoclase) bands, very rich in feldspar, show continuous variations in composition between the outer and central parts. Such variations are due to the nature of the femic minerals, represented solely by *amphibole* in those parts nearest the amphibolic bands, and then by amphibole accompanied by increasingly abundant biotite, until, in the inner parts of the light bands, dark mica becomes as frequent as the hornblende.

It is worth noting that in the sialic bands occurring in this zone, *potash-feldspar is totally absent.* This is a characteristic that has already been shown in the rocks of the plagioclase gneissic mass of Skoyo-Turmik and in the bands existing in its marginal belt.

THE ROCKS OF THE TURMIK VALLEY

The rocks occurring in the Turmik valley are of rather various type, as shown by the petrographic descriptions of the single samples gathered by me. But, if we combine in the same group all those rocks which, although different in grain, metamorphic grade, or in the quantitative ratio of different mineral constituents, nevertheless have obvious common characteristics (as happens in many amphibolites, prasinites and amphibolic gneisses), it is possible to produce a relatively simple picture of their succession in the field (1).

Taking for granted that the formation under study forms a large belt, which in the upper basin of the Turmik valley has a main trend parallel to the axis of the valley (NW-SE, dipping NE), but which in the middle basin makes a broad curve to an E-W direction passing into the contiguous Basha valley, where it again resumes a NW-SE direction, it can be said, in summary, that moving from SW to NE the successions is as follows: firstly, (on the right side of the valley) femic schistose rocks, mainly amphibolic, then (on the left side of the middle and lower parts of the valley) weakly metamorphic clastic sediments, and, finally, (on the left side of the upper and middle part of the valley), calcareous rocks.

(1) As it has been said in another part of this work (page 109) the succession of different terrains met in the field does not necessarily correspond to a stratigraphic succession, since we have noted the existence of folds of local importance which cause the repetition of some members of this series.

Before reviewing the geologic-petrographic characteristics of the above mentioned rocks, I would again emphasize that the rocks of this formation, although very extended in the southern section of the zone mapped by me, are much compressed and reduced in extent in the most northerly parts, that is to say in the zone of the Stak-la.

Schistose basic rocks.

The schistose femic rocks occur principally on the right side of the Turmik valley, joining up towards the south with the plagioclase gneissic mass of Skoyo-Turmik and combining westwards with analogous terrains, which form part of the zones of Twar and Askore. They can be considered, in part, as the direct continuation of the schistose femic rocks occurring on the right side of the Indus valley, between the village of Tungas and the mouth of the Turmik valley, but are, on the whole, more femic than these, and are not crossed by thin or thick sialic dykes.

In the lower part of the valley, north of Dasu, a little above the valley floor, the more common type of femic rocks appear to be laminated rather than schistose, as a consequence of tectonic movements and sometimes mylonitized and diaphtoritic, as is shown by the chloritization of the original amphibole (54 PZ-88). Also the dark compact rocks, corresponding to *melaphyres* (basalts) (54 PZ-87 and 91), which stand out from the schistose rocks with which they are sometimes intimately associated, are at some point characterised by surfaces of movement (slip), along which they are transformed into *serpentine* (54 PZ-90) (Plate 14, fig. 3).

At greater heights, near the zone of contact with the mass of plagioclase gneisses and farther towards the north-west, that is, in the middle and higher parts of the left side, up to the area of Askobur Lungma, occurs a rather monotonous sequence of prevailingly amphibolic rocks.

These are for the most part *epidote amphibolites* (Plate 13, fig. 2), *amphibolites* (Plate 13, fig. 1), or *amphibole or epidote-amphibole gneisses* with variable grain, nearly always with a neatly schistose texture. Amphibole is represented almost exclusively by green *hornblende*, which appears for the most part as single crystals distributed regularly amongst the other minerals, while less frequently it is associated with other amphibolic particles lacking any definite orientated disposition and in a few cases it forms some small patches.

The *epidote*, always present in remarkable quantities, is generally represented by ferriferous members, but sometimes by *clinozoisite*, which in some facies can be the predominant mineral, and much more rarely by *zoisite*. A characteristic common in all these rocks is the low An content of the plagioclases, corresponding, generally, to oligoclase 15°/₀ An, and in some cases still more albitic. For this reason it can be said that the rocks in this zone have a certain prasinitic character, even though I have not found any real prasinite.

With these predominant rock types are associated also *micaceous amphibolites*, *micaceous-amphibolic gneisses*, *biotite-epidote gneisses* (Plate 11, fig. 1) and *biotite gneisses* (Plate 13, fig. 4), which although corresponding to slightly less femic members show, for the most part, similar characteristics.

Much less common are the *actinolite-epidote schists rich in clinochlore* (54 PZ-95) (Plate 14, fig. 2), but also containing a certain quantity of quartz, and other non-schistose rocks formed exclusively of an amphibole of the *tremolite-actinolite* type distributed in a matrix of fine-grained *zoisite* crystals (54 PZ-96); I have tentatively attributed them to weathered porphyrites.

Finally, I will mention a particular type of rock observed near the mouth of the Askobur Lungma in the Turmik valley, immediately west of a calcareous band and corresponding to a *gneiss* of a light green colour, in which can be seen *amphibolic bands* alternating with light bands of *sodic plagioclase* together with small quantities of *quartz*, *chlorite*, *epidote* and *amphibole*. Large *quartzose and plagioclasic patches* develop among these minerals. The plagioclasic *patches* can be formed either with the combination of sodic plagioclases of considerable dimensions without any definite shape and rich in inclusions of biotite and epidote, or of an aggregate of small plagioclasic particles each having an optical orientation slightly different from that of the surrounding particles, so that a patch with the appearance of a ill-defined porphyroblast results. Also these aggregates include quartz, chlorite and epidote.

It should be noted that the fine-grained acicular facies of the amphibolic rocks which characterize this zone, are very similar in appearance to some rocks observed in the Twar zone (54 PZ-18) and in the Indus valley, near Tungas (54 PZ-9), but they differ by reason of the fact that these latter have a more calcic plagioclase.

The facies with a coarser grain have been observed in the upper branch of the Turmik valley below the Stak-la (53 PD-19) and in the higher parts of the Askobur Lungma and have a different composition to those occurring in the remaining parts of the valley. They are, in fact, rocks of a higher metamorphic grade, as is shown by the presence of a plagioclase 30°/₀ An and by the abundance of *garnet* (Plate 13, fig. 3). These rocks are very similar to those occurring in the Askore valley (54 PZ-34 and 35), of which, in fact, they represent the direct northward continuation, being separated from them only by the high un-named peaks which dominate the southern side of the Stak-la zone.

The transition from the prasinitic fine-grained amphibolic types, to the coarser-grained, garnetiferous or non-garnetiferous types, occurs gradually from south to north and from east to west, but the most rapid variations, which are therefore more evident in the field, are met in the upper part of the valley.

The transitions between this belt, formed almost exclusively of amphibolites, and the adjacent belt, formed mainly of rocks of sedimentary origin, is also gradual. It must be understood that in a sense the gentleness of this transition results from the fact that the amphibolic rocks and the rocks of sedimentary origin are interbedded for a considerable distance, and are sometimes so intimately mingled as to render impossible any distinction between the two belts.

Mainly schistose basic rocks also occur between the two larger calcareous bands which run uninterrupted for many kilometres from the upper Turmik valley to the Basha valley. These rocks are very similar to those just described, the main types corresponding to *prasinitic-amphibolites* more or less *epidotic* or to *amphibole-biotite schists* etc. (53 PD-21 a and 21 b; 54 PZ-128).

Between these better known and more frequent types, however, other rocks with particular features (53 PD-21) corresponding to *light whitish laminated gneisses*, which include very thin biotitic bands, are found. In these can be distinguished a fine-grained aggregate formed of *quartz*, *sodic plagioclase*, *biotite and muscovite*, and large crystals, which can be formed either solely of *albitic-oligoclasic plagioclase* (54 PZ-129) rich in sericitic inclusions and also disposed transversally in respect of the surfaces of schistosity of the rock, or of *epidote* and *plagioclase* 25-30°/₀ An (53 PD-21) combined in roundish or lenticular patches and coated by the fine-grained bands.

CLASTIC WEAKLY METAMORPHIC SCHISTS.

The outcrops of scarcely metamorphic schistose rocks of obvious sedimentary origin and clastic nature form a large portion of the left side of the lower Turmik valley and in some places extend, for a brief distance, on to the opposite side. It cannot however be said that they form a continuous belt interposed between the amphibolitic and the calcareous belts but rather a great irregular lens, elongated according to the prevailing direction of the formations of the Turmik valley. Furthermore, the boundaries of these terrains are not very easy to draw and either because of the reasons given above (intimate mingling with other terrains), or because of the increasing metamorphism from south-east to north-west, (i. e., along the strike of the formation under study) these rocks lose their peculiar features and assume a different appearance, so similar to that of some amphibolic schists as to make it difficult to recognise them immediately in the field.

The rocks that definitely belong to this group, correspond to *arenaceous phyllites* and to *conglomeratic schists* and occur over a large area on the left side of the valley, between the villages of Smurdo (a little north of the mouth of the Turmik river in the Indus valley) and Hurimul (in the middle Turmik valley, near the mouth of the "nala" that comes from Ganto-la). Here are also found, in small quantities, *fine-grained amphibole schists* (54 PZ-84), and slightly metamorphic *fine-grained compact porphyrites* (54 PZ-85).

In the more southerly parts of these outcrops, a little north of Smurdo, are found initially metamorphic rocks, corresponding to *phyllitic sandstones* (54 PZ-83) rather than to phyllites. The texture of the original sediments is still recognizable in these rocks. Macroscopically they show a greenish colour and a definite schistosity attributable to the presence of small chlorite particles. The fundamental constituents are *quartz*, an *albitic plagioclase* and *epidote* in very fine-grained particles.

Calcite is found in variable quantities and is, very probably, of later origin.

Rocks of this type are also found farther north, but become progressively richer in micaceous minerals and decidedly more schistose, thus changing into *arenaceous phyllites*, which also occur in the opposite side, near the valley bottom, close to the village of Kushumal. In each case, the phyllitic sandstone and arenaceous phyllites include rare quartzose streaks or lenses.

The phyllites which occur on the right side of the valley, near Kushumal, have been affected by tectonic movements in the same way as the femic rocks (amphibolites and melaphyres) occurring a little further south, along the same zone of movement. Among the particular facies of this zone should be mentioned a *phyllite* with thin alternating *quartzose-feldspathic* and *muscovitic-sericitic-chloritic* bands, rich in large crystals of *albite*, *quartz* and *calcite*.

Beyond Kushumal, on the left side of the valley, a belt of *conglomeratic schists* is developed, which runs approximately from east to west. The transition between the arenaceous schists and conglomeratic schists is almost un-noticeable; at first coarse grains or very small pebbles (54 PZ-103) appear on a light, very fine micaceous matrix, then above 2,800 m (9,200 ft) some irregularly distributed pebbles, increasing in size but never exceeding 2 cm in length, are observed (54 PZ-104, 105, 106, 107). In some cases beds particularly rich in coarse elements are clearly definable. These are distinguishable from the remaining parts, poor in or devoid of pebbles, which varies in thickness from a few centimetres to several decimetres. In some cases, the surfaces of foliation of these rocks are nearly perpendicular to the bedding.

The finer parts of these conglomeratic schists have a similar composition to that of the arenaceous phyllites just described, and the coarser elements mainly correspond to serpentinites and amphibolites similar to those occurring elsewhere in the Turmik valley. However I am not sure to which rocks of this formation should be attributed the pink or grey-brown pebbles which accompany the darker ones and which sometimes are more numerous than these.

I was not able to discover if the conglomeratic schists also occur west of Kushumal, that is on the left side of the valley, because here the great extent and thickness of the moraines makes observation very difficult. It is probable though that these psephitic rocks represent a local facies, which passes laterally into other more common types.

The conglomeratic schists give place, higher up, to fine-grained compact rocks of a light green colour, corresponding mainly to *phyllites*. These are easily distinguishable from those occurring farther south by the almost universal presence of *large rhombohedral crystals of carbonate*, as well as by their very infrequent schistosity. They are not, however, limited to the relatively narrow zone in which the conglomeratic schists appear, but occur all along the middle and upper Turmik valley, following the trend of the thick calcareous beds with which they are frequently associated. Partly for this reason, and partly because of the presence of carbonates, these rocks will be considered as a characteristic type of the calcareous Turmik series even though they have an obvious clastic origin.

THE CALCAREOUS SERIES.

Phyllites rich in porphyroblasts of carbonate occur immediately south-west and south of the first belt of the calcareous formation which forms the greater part of the left side of the valley. They also occur, however, in discontinuous patches, north-east of the same belt and north-east of the calcareous band which occurs on the right side of the upper valley and which seems to reach the larger calcareous belt north of the mouth of the Askobur Lungma.

The large crystals of carbonate which macroscopically enable these rocks to be easily recognised very often disappear in the superficial parts of the outcrops, leaving empty spaces roughly rhombohedral in form. These are equally characteristic, and are often partially filled with a dark reddish material, corresponding partly to limonite.

Microscopic observation (54 PZ-110, 111, 112, 112a) shows that the matrix is formed of a fine-grained aggregate of granules of *quartz* and *plagioclase* (the latter in smaller quantities), of *muscovite*, *phengite*, *chlorite*, and sometimes *biotite* flakes, and of grains of *epidote*. The lamellar minerals generally occur in subparallel planes and can be fairly abundant. The same can be for the epidote, which in some cases represents the main mineral of these rocks (54 PZ-122 and 123).

The large crystals of *carbonate* generally have a rhombohedral shape, but can also form patches with no defined shape. In either case they possess frequent inclusions of those minerals which form the matrix of the rocks: quartz, plagioclase, micas, chlorite, epidote and, usually, an abundance of iron oxide. The growth of these larger poikiloblastic particles has caused the displacement of the quartzose-micaceous bands of the matrix (Plate 14, fig. 4).

Intermingled with these *phyllites rich in carbonatic porphyroblasts* are found other types of rock, which, although possessing some variations in mineralogical composition, have a very similar appearance. I will mention some which are particularly interesting either for their diffusion or for their petrographic characteristics.

One sample (53 PD-18a) presents a locally intense reddish, rather than the usual greenish colour, and is dotted with the usual cavities filled up with a brownish material. Under the microscope, however, I have found no trace of carbonate, the large crystals being formed instead by a plagioclase about 15°/₀ An. (N. B. I have only one sample of this type). Also the aggregate of the matrix has a different composition, consisting of localized quartz patches and an abundance of *sodic plagioclase* and prismatic *manganesiferous epidote* crystals of a reddish colour, and very pleochroic.

The *plagioclasic porphyroblasts* completely lack any defined limits and enclose muscovite, epidote and quartz (in the same way as has been observed for the carbonatic crystals). The epidote shows a distinct pleochroism and reddish colour, comparable to the epidote of the matrix.

More common are the rocks very rich in ferriferous epidote and devoid of crystals of carbonate. In one of these facies (54 PZ-115), formed mainly of *epidote*, large crystals of actinolite are developed.

Very rarely, however, one finds in these belts interbeddings of *chlorite schists* which include large *carbonate* particles (54 PZ-126).

The calcareous rocks, which succeed the arenaceous phyllites rich in carbonatic porphyroblasts, form two large parallel belts separated by outcrops of mainly schistose basic rocks which have already been mentioned.

I can say little of the larger northern belt, occurring in the highest parts of the left side of the upper Turmik valley, and on the right side of the Basha valley, as far as the village of Chutrun. Direct observations, made exclusively on the side of the Basha valley (between Matuntoro Klas and Chutrun), enable me to say only that the predominant facies correspond to *light limestones*, not usually very crystalline, while *dark limestones*, *calc-schists*, and the corresponding laminated types also occur, and that the strike of the beds changes from E-W in the upper part of the valley to NW-SE in the lower part.

I was able to get more information from the observations on the first calcareous belt, the thickness of wich is doubled by the presence of a steep anticline easily distinguishable in the canyon of the Blanzgo Lungma. Here, in fact, the more or less epidotic carbonatic phyllites which are succeeded at the mouth of the canyon by some light saccharoidal limestones (54 PZ-116) not more than 100 metres (300 ft) thick are themselves succeeded by slightly argillaceous *dark limestones*, which are at first interbedded with lighter types, but which later, alone, are about 300 m (1,000 ft) thick. Apart from these uniform compact facies (54 PZ-117), are found facies crossed in all directions by very small white veins of calcite (54 PZ-118) (sometimes so intensely folded as to resemble the ptigmatic veins of some migmatites), and more or less laminated facies. This series is found again in inverted order from the centre of the canyon to the point upstream where it widens into a large valley where *arenaceous epidote phyllites* and schists rich in epidote and chlorite, resembling the carbonatic phyllites occurring at the mouth of the same canyon, are found.

It is worth noting that on this northern flank of the anticline calcareous *schistose conglomerates* (54 PZ-120) with a matrix rich in epidote have been observed, and that other fine-grained phyllitic conglomerates have been observed among the common type of arenaceous phyllites.

Further south-east of the Blanzgo Lungma, in the valley from Hurimul to Ganto-la which diagonally intersects the same calcareous belt, the dark limestones seem to be less extensive than those observed here.

I could not follow the continuation of these limestone beds, either towards the north, where they seem to form some high peaks east of the Stak-la, or in the low Basha valley, where, having assumed a south-east trend before reaching the valley bottom, they must, in all probability, come in contact with the tonalitic rocks which occur west of Tisar. Again in the Basha valley, near Chutrun, the limestones are succeeded towards the north and north-east by micaceous gneisses, of which I have no sample.

GENERAL CHARACTERISTICS OF THE SCHISTOSE FORMATION OCCURRING BETWEEN THE ASKORE VALLEY AND THE SHIGAR VALLEY AND CONCLUSIONS

In the chapters dealing with the plutonic masses occurring in the Askore-Twar zone and in the Indus valley, between Skoyo and the Turmik valley, I have limited myself to giving the essential geologic-petrographic details of the metamorphic rocks in which such masses are enclosed. To these paragraphs, concerned with a discussion of the characteristics of all the prevailingly amphibolitic schistose formations, have been deferred indications of their original nature and of the processes which have resulted in the formation of their actual facies.

This discussion will, in the main, consider not only the data already given for the areas of the Askore, Twar and Turmik valleys and for a long stretch of the Indus valley, but also the observations made in the Shigar and Braldu valleys, where rocks similar to those forming the greater part of the area now indicated, occur. This is, as can be seen, a very extended formation occupying nearly the whole of that part of Karakorum which forms the subject of the present work, with the exception of the Stak valley basin and a part of the left side of the Shigar valley. Its continuity is interrupted by plutonic basic and acid masses, the largest of which occurs on the right side of the Shigar valley.

On the basis of present informations the most common rocks of this formation seem to be the following.

Basic schists.

The rocks corresponding to the highest metamorphic grade are *labradorite-biotite-garnetiferous gneisses*, sometimes rich in sillimanite, which occur widely in the more southerly part of the Indus valley mapped by me and in the lower Shigar valley that is south of the amphibolitic outcrops; probably they formed at the expense of basic volcanic rocks, weathered with production of argillaceous minerals. Other highly metamorphic rocks are the *garnetiferous amphibolites*, always fairly rich in epidote and poor in plagioclase (andesine). These are localized in the Askore valley and in the upper part of Turmik valley, that is along the western margin of the schistose formation now under discussion.

Real amphibolites, *epidote amphibolites*, and *amphibole and epidote-amphibole gneisses* are the most common types and are particularly frequent on the right side of the Turmik valley. The *amphibole-biotite or biotite-amphibole gneisses*, more or less rich in epidote, are interbedded with amphibolites devoid of biotite and are very frequent, and, in fact, predominant in the section of the Indus valley between Gurbidas and the mouth of the Turmik valley.

The plagioclases of all the facies now indicated, except for a few exceptions, are of somewhat sodic type.

The *actinolite and anthophyllite schists* represent a facies (*albite-epidote amphibolite facies* of Eskola) transitional between the amphibolitic rocks of the mesozone (*amphibolite facies* of Eskola) and the facies of the epizone.

The *serpentinites*, *chlorite schists* and conglomeratic schists, common in the Turmik valley, and especially in Bauma-harel Lungma (in the Shigar basin) are the most typical facies of the epizone (*greenschist facies* of Eskola).

The basalts (melaphyres), often weathered or showing signs of initial metamorphism, are rather rare.

All these rocks derive from more or less intense transformation of *basic rocks* of basaltic and dioritic composition, as shown by chemical analysis, with either sialic or femic variations. The frequent and intimate interbedding with sedimentary rocks of a different nature indicates they are derived, in most cases, from *volcanic products*, *lavas* or, still more often, *tuffs*.

The hypothesis could perhaps also be advanced that part of the volcanic products were of spilitic type, which would also explain the relatively sodic composition of the amphibolites of some zones (Turmik valley) (1). Such an hypothesis would be supported by the presence, among the sediments interbedded with the amphibolites, of often pure siliceous rocks (quartzites), and of rocks containing large quantities of manganesiferous epidote. In fact siliceous deposits (chert) and manganesiferous deposits often accompany the effusion of spilitic lavas. Again, it should be noted that among the samples gathered by G. DAINELLI (1934, page 622) in a formation which, very probably, corresponds to those now under discussion, were found keratophyres, that is, those effusive rocks which normally accompany the spilitic manifestations characteristic of the final phases of a geosyncline.

In some cases (Askore valley, see page 56) it is not possible to establish if the amphibolites derive from the metamorphism of volcanic rocks or of intrusive rocks of similar composition. One cannot exclude the possibility that a small part of the amphibolites may derive from impure sedimentary calcareous-dolomitic rocks or from tuffaceous limestones.

CARBONATIC ROCKS.

These are represented by *marbles*, *calc-schists*, *limestones*, *dolomitic limestones and slightly metamorphic argillaceous limestones*. The carbonates, are also present, in greater or lesser quantities, in other rocks, as, for example, the phyllites rich in *carbonatic porphyroblasts* which are found in the Turmik valley.

The calcareous or dolomitic-calcareous rocks interbedded with other types form large bands, with a general SE-NW trend, thus retaining their characteristics over great distances. Large roughly subparallel bands run from Mulakor to Tungas, in the Indus valley, from the upper Turmik valley to the lower Basha valley, from Koser Gunge to the bottom of the Shigar valley and, according to A. DESIO (1930) and G. DAINELLI (1934) from Chokpiong to Pakore (Hoto), in the Braldu valley.

PELITIC AND ARENACEOUS SCHISTS.

These are represented by *micaschists* and *garnetiferous paragneisses*, *arenaceous phyllites* and *phyllitic sandstones* rich in epidote. Except in the Turmik valley, where the phyllitic rocks are remarkably extensive, these pelitic-

(1) The particular richness in soda of some rocks of the amphibolitic formation is due to metasomatic processes.

arenaceous schists, for the most part of modest thickness, are frequently interbedded with other rocks.

Between these rocks of clastic nature the *quartzites* and the *conglomeratic schists* can also be mentioned.

Many of these pelitic-psammitic rocks have been formed at the expense of volcanic material.

This brief review of the principal types of volcanic-sedimentary formations under study shows how they correspond to metamorphic rocks of the epi- and mesozone.

The variations of metamorphic grade do not occur in a regular way. On the contrary rapid changes of metamorphic facies both parallel and perpendicular to the direction of the planes of foliation of the rocks sometimes exist. In the Turmik valley, for example, where the volcanic-sedimentary rocks have a NW-SE trend, nearly parallel to the axis of the valley, the rocks of the higher epizone, occurring in its middle and lower parts, change more or less rapidly in all directions to facies of the mesozone. It could be said, therefore, that the isogrades have, in general, a capricious trend and often close up on themselves. Judging from the general tectonic situation and from the relations with the plutonic rocks enclosed in them, it can be said that the higher grades of regional metamorphism are met either in the zones of more intense deformation and dislocation (e. g., the above-mentioned zone of the Stak-la, where, as I have already said, the volcanic-sedimentary complex is strongly compressed) or in the zones near the plutonic masses (sialic and basic masses, sialic dykes etc.).

CHEMICAL VALUES

In order to obtain useful information on the chemistry of the schistose basic rocks which, as it has been said, form the most common series of the large metamorphic formation now under discussion, chemical analyses have been made of three samples of amphibolites and of amphibole and amphibole-biotite gneisses, i. e., the most frequent facies among the basic schists. So as to be able to find variations of composition of these amphibolites samples coming from widely dispersed zones have been chosen. One (Twar amphibolite) was taken several hundred metres from the highest and most easterly outcrops of the dioritic-noritic Twar mass, another was taken near Gurbidas, in the Indus valley, where the amphibolites form large isolated patches in the granitic rocks (i. e., they form the paleosome of an agmatitic formation often with extremely large elements); the third was taken near Chongo, in the Braldu valley, and represents a particular type, rich in sphene and apatite.

To these samples can be added a fourth, taken in the marginal agmatitic belt which divides the mass of plagioclase gneisses occurring between Skoyo and the Turmik valley from the surrounding rocks.

The weight percentage values and the petrochemical data deduced from them are combined in Table 17.

TABLE 17

BASIC SCHISTS OF THE VOLCANIC-SEDIMENTARY FORMATION

ANALYSED ROCKS

Locality	Petrographic classification	Chemical classification according to the Niggli's magmatic types
1. – The Indus valley, at the height of 3.500 m (11,500 ft) above Mulakor.	Amphibolite (54 PZ-70).	Between the *normal gabbroic* and *c-gabbroic types* and *the normal gabbrodioritic type.*
2. – The Indus valley, a little to the north of Gurbidas.	Amphibole-biotite gneiss (amphibolite) (54 PZ-7).	*Normal gabbrodioritic type.*
3. – The Braldu valley, near Chongo.	Amphibole-biotite gneiss (amphibolite) with sphene and epidote (54 PZ-138).	Between the *miharaitic type* (gabbroic magmas) and the *leucomiharaitic type* (leucogabbroic magmas).
4. – The Indus valley, to the west of Dasu.	Biotite-epidote gneiss (54-PZ 17a).	*Normal dioritic type.*
ROCKS FROM THE SOUTHERN BALTISTAN		
5. – The Dras valley, to the SW of Khahr (collected by A. Desio, 1929).	Amphibolite (P. Comucci, 1938, pag. 193).	Between the *gabbroic types* and *the pyroxenitic and hornblenditic types.*
6. – The Burji-la valley, to the South of Skardu (collected by G. Dainelli).	Amphibole-chlorite schist with epidote (P. Aloisi, 1932, pag. 208).	—
7. – The Burji-la valley, near Karol Marpo (collected by A. Desio, 1929).	Amphibole porphyrite (P. Comucci, 1938, pag. 161).	Between the *gabbroic types* and the *gabbrodioritic types.*
8. – The Burji-la valley, near Karal Marpo (collected by A. Desio, 1929).	Trachyandesite (P. Comucci, 1938, pag. 167).	*Normal dioritic type* (attributed by P. Comucci to the essexitic magmas).

(TABLE 17 - Continued)

CHEMICAL COMPOSITION

ANALYSED ROCKS

	1 Analyst: B. Zanettin	2 Analyst: B. Zanettin	3 Analyst: B. Zanettin	4 Analyst: C. Viterbo
SiO_2	49.83%	51.73%	45.98%	57.74%
TiO_2	0.53	0.48	3.72	1.12
P_2O_5	0.24	0.09	1.67	0.31
Al_2O_3	17.10	16.67	15.05	17.25
Fe_2O_3	2.11	1.62	2.96	2.62
FeO	6.54	4.76	8.59	3.83
MnO	0.25	0.10	0.24	0.09
MgO	8.32	8.60	3.62	3.00
CaO	9.61	8.73	10.28	5.53
Na_2O	3.35	4.04	3.00	4.11
K_2O	0.35	1.05	2.90	2.63
H_2O+	1.60	1.76	2.26	1.53
H_2O-	0.06	0.02	0.08	0.09
	99.89	99.65	100.35	99.85

ROCKS FROM THE SOUTHERN BALTISTAN

	5 Analyst: C. Comucci	6 Analyst: C. Comucci	7 Analyst: C. Comucci	8 Analyst: C. Comucci
SiO_2	51.10%	48.14%	50.62%	48.70%
TiO_2	0.80	1.99	3.52	2.20
P_2O_5	n.d.	n.d.	n.d.	n.d.
Al_2O_3	14.34	14.69	12.39	17.15
Fe_2O_3	4.21	4.52	3.98	2.46
FeO	4.78	3.76	8.66	4.70
MnO	0.20	0.12	0.19	0.19
MgO	7.88	9.67	10.08	3.59
CaO	12.30	12.37	6.24	10.38
Na_2O	2.36	0.72	3.01	4.59
K_2O	0.99	0.71	0.54	2.08
H_2O+	1.19	3.56	1.54	1.38
H_2O-	0.06		tr.	0.14
CO_2	—	—	—	2.62
	100.21	100.25	100.77	100.18

NIGGLI'S values

Analysed rocks	*si*	*al*	*fm*	*c*	*alk*	*k*	*mg*
1. Amphibolite from Mulakor	144.6	23.2	45.3	23.7	7.8	0.07	0.63
2. Amphibolite from Gurbidas	123.6	23.5	43.2	22.3	11.0	0.15	0.71
3. Amphibolite from Chongo	116	22.4	37.8	27.8	12.0	0.39	0.36
4. Biotite-epidote gneiss from Dasu	165.9	29.2	36.6	17.0	17.2	0.33	0.58

(TABLE 17 - Continued)

Rocks from the southern Baltistan	*si*	*al*	*fm*	*c*	*alk*	*k*	*mg*
5. Amphibolite from Dras	117.49	19.53	43.78	30.26	6.63	0.21	0.62
6. Greenschist from Burji-la	109.16	19.62	47.72	30.04	2.6	0.39	0.68
7. Amphibolic porphyrite from Karal-Marpo	118.92	17.07	59.80	15.66	7.47	0.09	0 56
8. Trachyandesite from Karal-Marpo	141.3	29.27	32.23	21.78	16.72	0.23	0.48
Niggli's magmatic types							
Gabbroic magmas:							
Normal gabbroic type	108	21	51	22	6	0.2	0.5
c-gabbroic type	100	25	46	25	4	0.1	0.7
Miharaitic type	130	23	42	27.5	7.5	0.2	0.5
Leucogabbroic magmas:							
Leucomiharaitic type	140	26.5	38	26.5	9	0.25	0.45
Gabbrodioritic magmas:							
Normal gabbrodioritic type	130	23	44	22.5	10.5	0.2	0.5
Dioritic magmas:							
Normal dioritic type	155	30	35	21	14	0.3	0.5

As can be seen the composition of the four amphibolites analyzed alternates between that of the *gabbroic magmas* and that of the *dioritic magmas*, corresponding almost constantly to the "normal types" of the different groups of magmas.

The samples taken in the Twar zone and near Gurbidas correspond to *gabbroic*, or at least *gabbrodioritic types*, and show close similarities. The most striking difference is represented by the total content in alkalis (3,70% for the Twar amphibolite, 5,09% for the Gurbidas type). Since the Braldu valley sample, apart from having an uncommon composition in respect of the high values of TiO_2 and P_2O_5, can be put in the group of gabbroic or leucogabbroic magmas, it can be said, (despite the uncertainty due to the small number of chemical analyses made) that between the basic rocks of this schistose formation the more femic terms, that is the gabbroic and gabbrodioritic facies, seem to predominate.

It can be seen also that some of the gabbroic rocks, although belonging perfectly to the alkali-calcic series, show some rather high values of Na_2O (up to 4,04%) while the values of K_2O are very low. This causes the low values of *k* shown by the magmatic formulas.

The most sialic sample, corresponding to the normal dioritic type has a total content in alkali which is naturally higher than that of the normal gabbroic types (amphibolites of Twar and of Gurbidas), but this increase is due almost exclusively to the greater K_2O content. The fact that Na_2O maintains values almost equal in this facies and in the more basic facies makes me think that this strip of schists enclosed in the sodic persilicic rocks (plagioclase gneisses) has not suffered chemical changes by the processes which have created the enclosing sodic rocks.

It has already been noted how, over the whole area north of the calcareous belt which runs from Tungas to Mulakor, lighter amphibolitic rocks, corresponding to amphibole-biotite and biotite-amphibole gneisses are more frequent than elsewhere.

In order to establish the existence of genetic relations with other rocks occurring in the regions south of the territory now under examination (see discussion in the following pages), it is interesting to compare the chemical data of our amphibolites with those obtained by other authors on extrusive rocks of the volcanic-sedimentary series of southern Baltistan and of Ladakh, or on the metamorphic rocks certainly derived from them. These data are given in Table 17.

This comparison shows that an amphibolite gathered by A. DESIO south-west of Khahr, in the Dras valley, is very little different in composition to our amphibolites, corresponding, as do some of these, to "magmatic types" of the gabbroic group. The most obvious differences are caused by the very high CaO content (12°/₀ instead of 9°/₀ as in our rocks) and to the lower value of Na_2O (2,35°/₀ instead of 3-4°/₀).

Very similar in composition to the Dras amphibolite is a "porphyrite" (more exactly a chlorite schist rich in epidote associated to the "quartziferous porphyrites") from Burji-la, south of Skardu (taken by G. DAINELLI), which can thus be considered as belonging, together with the quartziferous porphyrites with which it is associated, to the formation of the basic schists occurring in our territory. This rock, which has a composition intermediate between that of the gabbroic magmas (pyroxenegabbroic type) and that of the pyroxenitic magmas, differs from our rocks by reason of the very low value of Na_2O (0,72°/₀).

From the Burji-la (Karal-Marpo) zone there is also an " amphibolic porphyrite" sample (taken by A. DESIO), which, chemically, shows so many points of comparison with our amphibolites (in Na_2O and in K_2O content and in the ratio between the alkalis), as to be assigned, like them, to types intermediate between the gabbroic and gabbrodioritic magmas (still without corresponding to any exact "magmatic type" because of the very low value of *al* and the very high value of *fm*). The most remarkable differences in comparison with our amphibolites are also found in the lower percentage of Al_2O_3 and in the different ratio between the femic oxides.

From the same locality comes an effusive rock, called "trachyandesite" by COMUCCI and assigned by him, on the basis of the magmatic formulas, to essexitic magmas. It seems to me that Niggli's values correspond very well with the characteristic values of the normal dioritic type of the group of dioritic magmas, and thus the rock can be referred to as an andesite or, more exactly, (using the common chronological classification) as a porphyrite, because these rocks, like those mentioned above from the zone of Burji-la and the Dras valley, are products retained from the Senonian effusions.

These comparisons show clearly enough the chemical similarity existing between the amphibolitic rocks occurring between the Askore valley and the Braldu valley and the effusive rocks of the volcanic-sedimentary Senonian series outcropping south of our area.

ANALOGIES WITH OTHER HIMALAYAN FORMATIONS

The amphibolites which occupy a large part of the area between the Askore and Shigar valleys show undeniable similarities with the amphibolites which towards the east, in the zone of Astor (and also towards the west, in the zone of Chilas) succeed the sialic gneisses of the Nanga Parbat massif. It could even be said that the rocks occurring in the most western part of our area (Askore-Twar zone) represent the direct continuation towards north of the basic schists of Astor, as I have already mentioned in another chapter (page 50).

The amphibolites of the Askore zone, and the rocks associated with them, change southwards to rocks of the same nature, but of lower and lower metamorphic grade and finally to the original unaltered rocks.

It has thus been possible (D. N. WADIA, 1937) to establish the exact stratigraphical and chronological succession of these terrains, whose most interesting characteristic is the intimate association of marine sediments with pyroclastic, volcanic, hypabyssal and plutonic rocks. They are represented essentially by well bedded, often argillaceous, volcanic ashes, rich in beds of chert, by tuffs, by agglomeratic slates with a matrix of volcanic origin, by sandstones, by "agglomeratic conglomerates", and by fossiliferous limestones of Cretaceous age (*Orbitoline*) (1). Basaltic or andesitic flows (2) are relatively rare.

(1) At one point (Dras) thin beds of Eocenic limestones (*Alveoline*) overlay the volcanic Cretaceous series.

(2) The scarcity of the lava-flows in relation to pyroclastic products is, lithologically, the best

These rocks are intersected by dykes, sills and femic masses (gabbros with diallage, norites, pyroxenites and serpentinites which should represent the intrusive analogues of the basic extrusions) and by large sialic masses, especially "hornblende-granite".

This volcanic-sedimentary formation, with which it is possible to correlate the metamorphic amphibolitic formation of the more northerly regions (Astor, Askore, Twar, and, by analogy, Turmik and Shigar), forms a continuous belt which extends from Astor (where it has a general NE-SW direction) to Dras (with a NW-SE direction).

Previous authors like R. Lydekker, C. S. Middlemis, and G. Dainelli had recognized in this latter area the existence of a belt of volcanic rocks associated with the sediments and followed the outcrops as far as the Indus valley (with a brief break between Dras and Kargil) and thereafter towards the southwest, along the upper course of the Indus river, for hundreds of kilometres.

G. Dainelli had defined, farther east, another belt similar in lithological characteristics and in age. This is parallel to the first and separated from it by elongated granitic outcrops a few kilometres thick and with a constant SE-NW direction, for many hundreds of kilometres. This second thin belt, continuing uninterrupted from SE to NW, gives way to schistose rocks, which in Baltistan (i. e., in the zone where the 1954 Italian Expedition worked) widen and cover a large area.

G. Dainelli (1933) on palaeontological evidence was able to assign this volcanic-sedimentary formation to the *Cretaceous* or, more exactly, to the *Senonian.*

As regards the "crystalline schists", that is the schistose rocks occurring mainly in Baltistan between the Askore and Shigar valleys, the same author thinks that they are very ancient *pre-Silurian* rocks. He is led to attribute this age to the schists because of the high crystallinity of the rocks and of the presence among the schists of calcareous-quartzitic bands which he called Silurian, on the basis of lithological analogies with formations of known age.

I have already shown how the metamorphic rocks of the Askore and Twar valleys (and therefore also those of the Turmik and Shigar valleys) must be equivalent to those of Astor, both in respect of lithological analogies and because of the probable topographic continuity of the outcrops. In other words *our rocks would represent the metamorphic product of the terrains of the*

way of distinguishing the volcanic Cretaceous series from the *Panjal volcanic series* (known as Panjal traps), which vary in age from Upper Carboniferous to upper Triassic. In the latter the lava flows are completely predominant (D. N. Wadia, 1937, page 157).

volcanic-sedimentary series of Cretaceous age (Senonian) recognised by G. DAINELLI, and D. N. WADIA and later by P. MISCH (1949).

The crystallinity of our rocks is not a valid reason for believing them to be very ancient because, as it has been said, in the Astor outcrops the progressive increase of regional metamorphism from south to north in the Senonian rocks is well proved. Moreover, G. DAINELLI (1934, page 625), had a chance to see that because of orogenetic activity, the basic Senonian rocks sometimes had assumed an evident schistosity and, in particular, that some amphibolites originated from gabbroic rocks.

Even the presence of quartzites in the calcareous bands occurring in the amphibolite formation is not necessarily indicative of Silurian age. The frequent presence of siliceous sediments (chert) in the Senonian volcanic-sedimentary series can easily explain the presence of quartzites among the rocks of our metamorphic formation.

I think one can definitely say that, since the limestones are always interbedded with amphibolites and green schists, they must be coeval with these.

One cannot absolutely exclude the possibility that more ancient series can also occur in the Cretaceous amphibolite formations as a result of tectonic complications. However, the only rocks in which I found no interbedding of amphibolites, greenschists or equivalent rocks, are the slates occurring on the left side of the Shigar valley. These slates, as it will be shown later on (chapter V page 155), correspond to the non-metamorphic series of *Senonian* or *Eocene* age, which in the area of the Ladakh Indus directly succeeds the volcanic-sedimentary formation. This fact is thus another decisive proof of the similarities existing between the above-mentioned volcanic-sedimentary formations of Dras and Ladakh and the amphibolitic formation occurring in the zone mapped by me.

I, therefore, maintain that the volcanic rocks, which form the two large parallel belts east of the Ladakh Indus, have been submitted to regional metamorphism advancing in intensity from south-east to north-west, so as to cause the appearance of crystalline schists.

In conclusion, the prevailingly basic "crystalline schists" occurring between the Askore and Shigar valleys, represent the direct north-west continuation of two belts of Senonian volcanic sedimentary rocks. In Ladakh these belts are parallel and border an elongated granitic mass. The eastern belt has a continuous SE-NW direction right into Baltistan while the western belt moves away from the first, enveloping, in a wide curve, the hornblende granite mass of Baltistan and then combines, through Dras-Chechri Kadal, with the amphibolites of Astor. These two very long belts come together in the zone mapped by me, where they are topographically extensive, due partly to their amalgamation, and partly perhaps to a repetition of the members of the series by folding, as seems to be proved by the numerous similar calcareous belts, with a general SE-NW trend, which occur from west to east.

The principal tectonic feature in the Askore-Shigar area could be the one indicated by G. DAINELLI (1934, page 992) for the Braldu-Shigar-Indus section, i. e., a series of folds with a SE-NW strike and a dip towards the NE.

The remarks now made concerning the volcanic-sedimentary series also apply to the intrusive basic rocks which occur, as various sized roots or dykes, within the formations of amphibolites and the associated rocks. In connection with this I have already mentioned the norites and hypersthenic diorites which form the basic Twar mass (page 38). Here it might be emphasized that intrusive rocks of the same type also occur near Tungas and near Basha, along the Indus valley (page 86).

According to G. DAINELLI (1934, page 622) the *volcanic and plutonic basic and sialic rocks of the igneous-sedimentary complex should be coeval*, i. e., *Senonian*, because it is maintained, various deposits "were formed promiscuously, both in the time and in the space". These deposits consisted of ashes, breccias, lava flows and magmatic injections, according to whether the igneous materials reached the ground surface or stopped, in their ascent, before having reached it. Volcanic and plutonic rocks would derive from a single basic magma, maybe of gabbrodioritic composition. Differences would occur because from the slightly more sialic types would be derived the volcanic rocks, and from the slightly more femic types would be derived the plutonic rocks (the plutonic rocks are, on the whole, more femic than the extrusive rocks) (G. DAINELLI, 1934, page 627).

According to D. N. WADIA (1937, page 159), *the plutonic basic and acid rocks should be post-Cretaceous and maybe post-Eocenic*, although they represent the plutonic equivalents of the volcanic materials.

Although I have no decisive data about this problem I assign a probable *post-Cretaceous age* (Eocene or post-Eocene) to the basic Twar mass, because the noritic mass, only slightly metamorphic in its eastern part, is surrounded by amphibolites and by other metamorphic rocks of the mesozone, which means that the volcanic-sedimentary series have suffered metamorphic action before the injection of the norites. I have already said (page 54), that a metamorphic action also acted subsequently to the formation of the basic mass which, in its turn, was submitted to a sometimes strong deformation.

The similarity of the views of G. DAINELLI and of D. N. WADIA about the close genetic relationships existing between the basic plutonic and volcanic rocks are confirmed, not only by the geological situation, but also by the data obtained from chemical analyses, made on samples taken from the Twar zone, which has already been mentioned (see also E. CALLEGARI & B. ZANETTIN, 1960).

Because of the complexity of the problem, comments about the sialic masses are deferred to the conclusions in the chapter dealing with the granitic-dioritic mass of the right side of the Shigar valley.

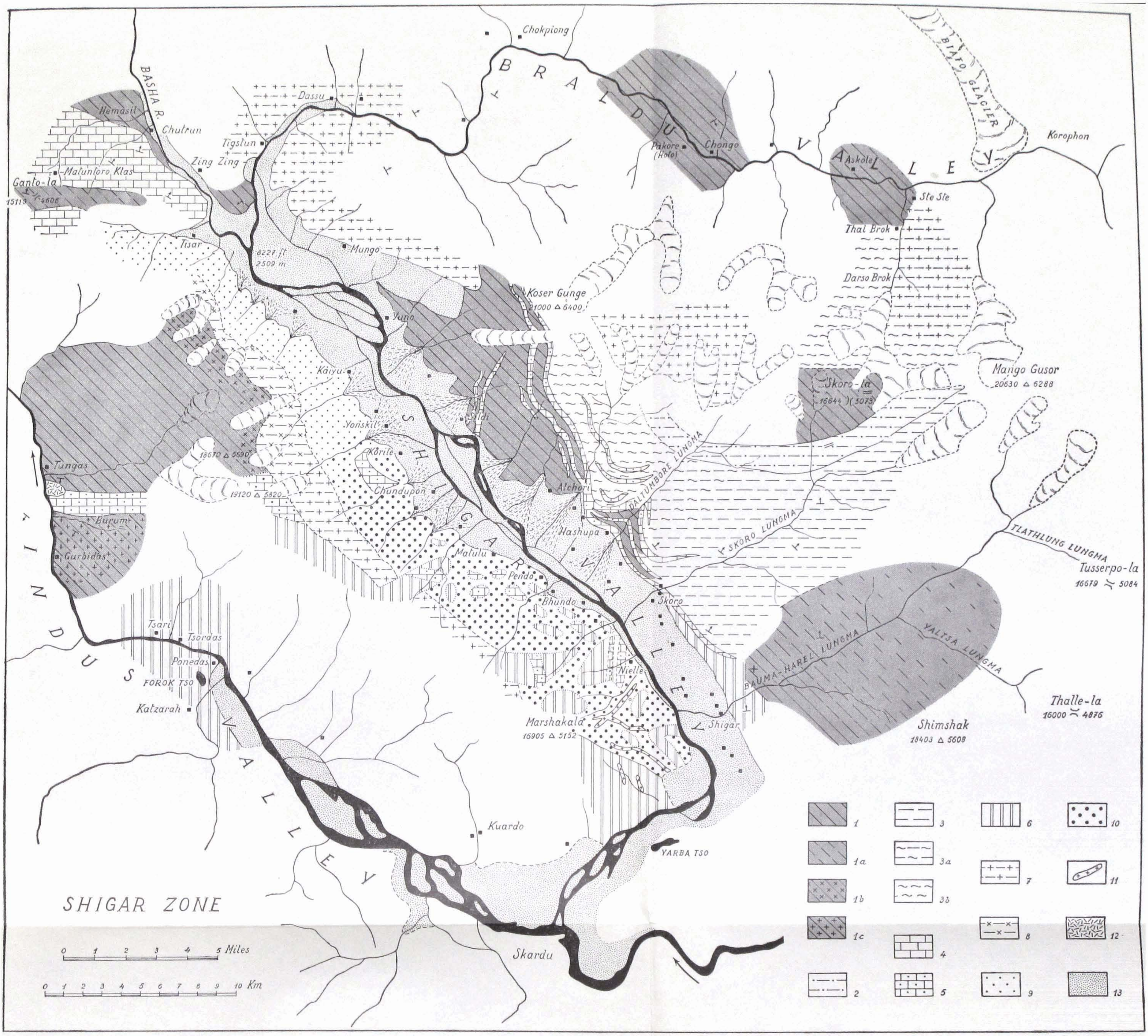

Fig. 10 - Geological sketch-map of the Shigar Valley zone.

1, 1 a, 1 b, 1 c - Cretaceous basic schists:

1 - Amphibolites, epidote-amphibolites, biotite-amphibole gneisses, etc.;

1 a - Greenschists (epidote-chlorite schists, chlorite-actinolite schists, etc.); id. with pyroxene and amphibole porphyroblasts (Bauma-Harel Lungma);

1 b - Amphibolites with plagioclase porphyroblasts.

1 c - Agmatites with elements of basic schists cemented by granitic gneisses.

2 - Arenaceous quartzites.

3, 3 a, 3 b - Cretaceous or Eocenic pelitic schists:

3 - Graphitic slates;

3 a - Albite-garnet-bearing graphitic phyllitic micaschists;

3 b - Micaschists.

4 - Limestones, dolomites, calcschists, etc.

5 - Marbles, calciphyres, calc-hornfelses.

6 - Biotite-garnet-labradorite gneisses, sometimes rich in sillimanite.

7 - Granitic gneisses and gneissic granites.

8 - Plagioclase gneisses.

9 - Tonalites.

10 - Gabbrodiorites and amphibole gabbros.

11 - Granite dykes.

12 - Hypersthene diorites.

13 - Moraine, alluvium and debris.

V

THE SHIGAR VALLEY ZONE

This zone includes nearly all *Shigar valley* proper, from its source to Skardu.

The Shigar valley has its origin at the confluence between the Basha and Braldu Valleys and runs for about 40 km in a south-east direction as far as the large village of Shigar. Here it makes a wide elbow and turns nearly at right angle (south-west), flowing into the Indus river near Skardu, after a further 12 kilometres.

The valley is wide along its whole length, and has very little slope.

The right side is very steep and intersected by many short valleys, difficult of access and characterized by a pronounced step in the terminal reaches. A high ridge, rising to 5,826 m (19,120 feet) parallel to the valley, divides, (as I have already said in the chapter on the Turmik valley zone) the Shigar valley from the trunk of the Indus river between the basin of Skardu and the mouth of the Turmik valley.

Entering the left side of the Shigar valley are valleys which become gradually longer as the mouth of the Shigar river is approached. This is because the divide between the Shigar valley (which has a south-east direction) and the Braldu valley (which has a general west-east direction) runs from west to east (i. e., parallel to the Braldu valley), and therefore trends progressively away from the bottom of the Shigar valley. This divide rises rapidly from 2,508 m (8,227 feet) at the source of the Shigar valley to 6,403 m (21,000 feet) at the Koser Gunge and then continues, still fairly high and dissected, reaching 6,290 m (20,630 feet) at Mango Gusor. A saddle in this ridge, the Skoro-la (5,074 m; 16,644 feet) connects the low Shigar valley with the high Braldu valley.

My mapping in this zone was somewhat exploratory. Nevertheless I was able to make more careful observations on the left side of the lower Shigar valley, between Hashupa and Shigar, along the whole of the Skoro Lungma (the valley leading to the Skoro-la) and along a good portion of Bauma-harel Lungma. On the remaining parts of the left side, above Hashupa, and along the whole of the right side, as far as Tisar, in the lower Basha valley I have limited myself to studying the foot of the outcrops, making observations and also gathering materials discharged from the lateral valleys. In the last part of the Shigar valley, between Shigar and Skardu, I made only rapid observations on the rocks occurring along the caravan-trail which passes near Yarba Tso.

Since the two sides of the Shigar valley show a different lithological composition, I prefer to consider separately the geological conditions and the relative petrographic characteristics shown by the rocks occurring on the right and on the left sides.

The most common rocks on the *right side* are of granitic-dioritic type surrounded by metamorphic rocks, which belong, at least in part, to the volcanic-sedimentary Cretaceous formation (and are perfectly analogous to those described in the chapter on the Turmik valley zone).

The zone of the Shigar Valley is the only one, among those described by me, whose essential geologic-petrographic characteristics were already known. It represents in fact the normal way of approach to the basins of Baltoro, Panmah, and Biafo, and was therefore crossed by all the caravan routes. Also the difficult Skoro-la route, which directly links the low Shigar valley with Askole, in the high Braldu valley, was repeatedly travelled over by alpinists and European scientists.

Among the travellers and geologists who have made more or less detailed observations and expeditions in this zone, I can recall, in chronological order: GODWIN AUSTEN, LYDEKKER, DAINELLI, DESIO.

THE RIGHT SIDE OF THE SHIGAR VALLEY

On the right side of the Shigar valley, or more exactly, between the village of Tisar, in the terminal part of the Basha valley, and the village of Nielle, in the lower Shigar valley, almost opposite the village of Shigar, i. e. for a distance of about thirty kilometres, rocks of granitic-dioritic type occur almost continuously. These have very variable petrographic characteristics and are surrounded by rocks affected in a greater or lesser grade by the regional metamorphism. These latter can in their turn be enclosed in the first in the form of different sized fragments and can have been submitted to the effects of the thermal metamorphism caused by them.

As I have already said, in this section I have limited myself to studying the foot of the outcrops, and thus only for the lower band of the right side can I give any sufficiently exact indication of the lithological constitution, while I have little direct information about the relations existing between the different facies of the granitic rocks between these and the surrounding rocks.

Visual observations, however, enable me to verify that the western contact between the granitic-dioritic mass and the surrounding rocks runs nearly parallel to the axis of the valley always keeping rather high on the valley bottom and rising slowly but continuously from north-west to south-east, until it reaches, and perhaps extends beyond the Shigar-Indus divide, a few kilometres north-west of the top of Marshakala (5,165 m; 16,905 feet). The southern boundary of this mass is a little irregular, occurring a little south of Nielle and rising nearly vertically from the bottom of the valley towards the Marshakala. The eastern boundaries are buried by the alluvium of the Shigar river. The most northerly outcrops of the granitic-dioritic rocks have been observed in the Tisar zone but here it was not possible to establish the nature and location of the contact.

PREVIOUS STUDIES

The only geologist who had made direct observations on the right side of the Shigar valley was G. DAINELLI (in 1913) who, like me, only went through the zone on or near the valley bottom. The descriptions given by him about the lithological and geological situation in this part of the valley are very brief probably because his observations were made during the winter, and also because granitic-dioritic rocks similar to those occurring here had already been described by him and discussed in connection with more southerly zones, where they form masses of greater extent.

I will quote in full the description given by G. DAINELLI. Concerning the diffusion of rocks of dioritic type he says (G. DAINELLI, 1934, page 650):

"I have noted numerous generally thin dykes on the right side of the lower Shigar valley, beneath the village of Nielle. These are injected into the gneissic schists. The small lateral valley, also on the right, which enters between Klakore and Pendo, discharges in its wide conoid, besides ancient (1) many-coloured schists, predominantly dioritic rocks, which must therefore play a remarkable part in the lithological formation of its basin. In fact, a little further on, just above Pendo, a large fragment of orographic terrace juts out from the mountain side. This is formed by *amphibolic-micaceous quartz diorite*. But a much greater outcrop is, without doubt, still higher up, towards the beginning of the Shigar valley at the confluence of the Braldu and Basha valleys. The small lateral valley entering at Chumik, in fact, seems to discharge from its right side granite and ancient crystalline schists, but from its left side exclusively — at least in appearance — dioritic rocks. Diorite only is discharged by the small lateral valley leading into Tsogo (here it is a *amphibolic-micaceous quartz diorite*), and also by the next valley which opens out at Tisar and here the rock is a *cataclastic micaceous quartz diorite*. The small valley of Tisar also discharges some quartzitic rocks, a sign that the dioritic outcrop terminates in its basin. It does not appear that there are any others in the Basha and Braldu valleys."

Concerning the diffusion of the granitic type of rock he says (G. DAINELLI, 1934, page 698):

"On the right side of the Shigar valley, a little above Khomo, the lateral valleys — after a zone of ancient crystalline schists — discharge only granite. The torrent that flows out at Chumik still discharges granite, but now already mingled with diorites which begin, here, to form the slope of the Shigar valley. A sample taken corresponds to a *two micas granite*. I did not observe other outcrops, except dykes which intersect the series of crystalline schists in the valley of Nielle."

In his 'geological sketch map' in the above mentioned work, DAINELLI indicates two distinct *granitic-dioritic* masses surrounded by the crystalline schist; the larger one, occurring between Tisar and Korite, and the smaller one, above Klakore.

(1) G. DAINELLI calls pre-Silurian all the different types of schists occurring in the Shigar-Braldu-Basha zone, with exception of the "calcareous-quartzitic" levels which he calls Silurian (see page 108).

GEOLOGICAL CONDITIONS AND PETROGRAPHIC FEATURES

THE COUNTRY ROCKS.

From what I have said above about the boundaries between the granitic-dioritic mass and the surrounding rocks, it can be seen that the latter have been observed only in the lower Shigar valley, near Nielle. All the other information about their nature and distribution is derived from the observation of the materials discharged from the lateral valleys and, indirectly, from the fairly precise knowledge of the lithological constitution and general trend of the country rocks (metamorphites of volcanic-sedimentary origin with prevalence of basic schists) in the Turmik valley and in adjacent parts of the Indus valley.

In general, then, the data at our disposal are sufficient to give an approximate picture of the topographic distribution of the most common types of surrounding rocks. It is not, however, always possible to make a distinction between the surrounding rocks and the enclosed rocks, by reason of the sparse observations made in the field.

Towards the north, near Tisar, the surrounding rocks are represented mainly by calcareous rocks; they represent the southern end of the calcareous belt which in the Turmik valley forms the left side above Hurimul. The most common materials observed were *calcareous conglomerates* (54 PZ-134) with slightly elongated elements of crystalline limestones cemented with a sparse greenish schistose matrix of chloritic-sericitic composition. Similar but less schistose rocks were also observed in Blanzgo Lungma (Turmik valley). Pure marbles are much rarer, as also are the green schists (54 PZ-133) and calcareous sandstones (54 PZ-135).

Passing southwards the calcareous rocks are succeeded by *greenschists* and even more by *amphibolites*. In the valley leading to Kaiyu, *amphibolites* occur together with few *marbles*. These *amphibolites* are compact, nearly black in colour, but nearly always patched by many irregularly distributed feldspathic crystals, which are sometimes of remarkable size. One example, corresponding to a *fine-grained biotite-epidote amphibolite* (54 PZ-265), has a schistose groundmass, with a very fine grain, formed with an aggregate of *hornblende*, *biotite*, *epidote*, *iron ore*, *quartz* and *plagioclases*. In this matrix the following can be distinguished:

many coarser-grained elongated lenses, formed with the combination of *amphiboles* of very variable composition and of *biotite*; patches of large *epidote* particles;

large *albite-oligoclase* (1) porphyroblasts in which remarkable quantities of biotite and epidote, and sometimes also of amphibole are enclosed. The growth of plagioclase porphyroblasts has caused the displacement of the minerals forming the fine-grained femic aggregate (Plate 17, fig. 1 and 2).

The rock seems to have undergone deformations and fracturing.

Another *fine-grained amphibolite* (54 PZ-267) is irregularly mottled by large feldspathic particles. It is formed essentially, and in some places exclusively, of *green hornblende*. The interstices left by the amphibole are occupied by small *plagioclases*, which fade into each other and include granules of epidote, biotite and amphibole. Biotite often accompanies the hornblende and become abundant where the plagioclase is abundant.

In this fine-grained matrix large ill-defined porphyroblasts of *albite-oligoclase* (2) stand out clearly. In the peripheral parts of these crystals large quantities of epidote and smaller quantities of biotite and amphibole are enclosed.

The most interesting characteristic is the definitely sodic composition of the plagioclase of the two amphibolites now described.

The *amphibolites* continue almost to Matulu. *Marbles* become very abundant in the scree only between Korite and Chundupon. Since in this part of the valley large portions formed with thin beds of limestones and calc-schists are clearly enclosed in the tonalitic-dioritic rocks, it is not possible for me to say whether at this point the calcareous rocks are also present between the surrounding rocks.

A little to the north of Matulu, in the scree discharged from the valleys, rocks of an argillaceous nature, sometimes alternating with thin beds of marl or limestone, appear together with marbles. The effects of contact metamorphism are always evident, to a greater or lesser degree, in these rocks which are represented by *spotted slates*, *calciphyres*, *biotitic schists* thinly interbedded with *calciphyres* and by *calc-schists*. A dark carbonaceous sample, corresponding to a *biotite-andalusite spotted slate* (54 PZ-271) with foliation surfaces discordant in respect of the original bedding, is formed essentially of *quartz*, *plagioclase* and *muscovite*. The minerals of neoformation are represented by

(1) $\gamma' < \omega_q$; optic sign always positive; the maximum extinction angles of albite twins measured in the zone $\perp$ (010) = 8^o-11^o = 8-12% An.

(2) $\gamma' < \omega_q$; optic sign always positive; the maximum extinction angles of albite twins measured in the zone $\perp$ (010) = 7^o-8^o = 12-15% An.

biotite and *andalusite*. The *biotite* is combined in elongated lenses in which the micaceous flakes have no orientated disposition. The andalusite is present in patches formed with the combination of small iso-orientated granular particles mixed with small granules of quartz (Plate 16, figs. 1 and 2).

Often the *pelitic schists*, rich in *biotite*, derived from the metamorphism of argillaceous-arenaceous sediments, give way to beds in which calciferous minerals such as *hornblende*, *epidote*, *pyroxene*, *sphene* and sometimes also *calcite* (54-Z 273) are associated with the *biotite*. The passage from the pelitic beds to the lime silicate beds occurs with the appearance, together with the biotite (which progressively diminishes, and sometimes disappears) of at first clinosoizite and later of actinolite, green hornblende, and pyroxene (Plate 16, fig. 3).

Simultaneously with the appearance of rocks of this type the relations between granitic-dioritic rocks and pre-existing rocks become more complex. Both act as enclosed and enclosing rocks and each, at some time, predominates over the other.

Streaks of calciphyres are frequent, as inclusions, between Matulu and Pendo. These are sometimes more or less completely transformed in *amphibolitic* rocks (54 PZ-275). Often they are thinly interbedded with *chlorite-biotite schists* slightly metamorphosed by contact; in such cases it can be seen how the metamorphic transformation occurs with greater speed in the impure calcareous beds than in chloritic beds.

Between Pendo and Bhundo the situation is still the same, but rocks of arenaceous-argillaceous origin seem to be more prevalent than the calc-silicate hornfelses and calciphyres, with which they are nearly always interbedded. A biotitic arenaceous schist (54 PZ-279) consisting of a fine-grained aggregate of *quartz*, *labradorite* and reddish *biotite* with a suborientated disposition, has long, concordant, coarse-grained lenses formed by remarkable quantities of *wollastonite* (1) with which *diopside*, *epidote* and sometimes a little *calcite* are also associated (Plate 16, fig. 4).

Near these calcareous lenses the biotite and quartz of the schist show coarser grain, probably as a consequence of the development of CO_2 in the course of the metamorphic transformation of the calcariferous material.

Rocks of this type are considered as belonging to the high grades of contact metamorphism.

South of Bhundo the schists enclosed in the plutonic rocks and metamor-

(1) $2V\alpha$ = about $30°$; $\alpha \Lambda c = 32°$.

phosed by contact, are always frequent. South of Trachil they become very abundant, with smaller quantities of crystalline limestones. They are *biotite-labradorite gneisses*, similar, on the whole, to other schists observed further north (54 PZ-279), but of greater lithological importance, because both their appearance and mineralogical composition show that they are equivalent to the terrains observed in the Indus valley (54 PZ-1; 53 PD-2) and on the left side of the Shigar valley (54 PZ-237-239-242-243). They show alternations of grey-ashy coloured beds and thin light quartzose beds.

The grey-ashy coloured beds are formed of *quartz*, *labradorite* and *biotite* in well developed flakes and with no definite orientation. *Garnet* and *tourmaline* are present in smaller quantities.

In the light beds, apart from quartz, there are a few *calcic plagioclases* partially substituted by more *sodic plagioclases*, and several large crystals of *andesine*, which include small fragments of *labradorite*.

Nearer Nielle bands of schists metamorphosed by contact, and sometimes intensely injected by sialic material, and marbles with irregularly distributed amphibolic bands are intermingled with dioritic rocks, in which patches of epidote and calcite are always enclosed.

A *biotite schist* (54 PZ-280), which shows alternations of very thin light and dark bands, owes its actual composition to the introduction of potash-feldspar. The dark fine-grained beds are formed of *quartz*, *labradorite* and *biotite* (comparable to the biotitic-labradoritic schists (54 PZ-279) collected between Pendo and Bhundo). Irregularly scattered in these are variable quantities of well developed *microcline* crystals, sometimes enclosing small particles of the other components of the rock. Locally the microcline becomes more abundant than the quartz and the labradorite, and sometimes it is the sole sialic mineral, thus forming bands of potash-feldspar and biotite. The light bands are formed of *quartz* and of lesser quantities of plagioclase. *Sphene*, *garnet* and *tourmaline* are also present.

Beyond Nielle, however, the rocks of sedimentary origin are represented by many very small inclusions of epidotic calciphyres. These are in strip form and nearly always elongated in one direction.

Schists, crossed by large granitic dykes, along the spur south-east of Mount Marshakala, and almost as far as Shigar, delimit the *granitic-dioritic* mass.

Among these schistose surrounding rocks are fine-grained *biotite paragneisses* (54 PZ-283) formed mainly of *quartz*, *sodic plagioclase*, *potash-feldspar* and *biotite*; also found in them are lenses or beds rich in *calcite*, in which *hornblende*, *actinolite*, *epidote* and *sphene* appear.

Summing up what has been said about the position of the different types of surrounding rocks it can be said that in the most northerly part of our zone *calcareous rocks* prevail. These are often conglomeratic, with a smaller quantity of *greenschists*. Farther south, as far as Matulu, however, the main rocks are *amphibolites*, always intermixed with *calcareous rocks*, which locally, between Korite and Chundupon, are very abundant. At Matulu appear *argillaceous-arenaceous schists* metamorphosed by contact. These are interbedded, often thinly, with *rocks of a calcareous or calcareous-argillaceous* nature nearly always altered to calciphyres. This formation continues as far as Trachil, sometimes with basic pelitic types (*biotite-labradorite gneisses*), sometimes with calcareous types predominating. Near Trachil the former are most common and are interbedded with bands of marble, at first rare, but towards Nielle becoming more abundant. Here they are associated with calc-silicate hornfelses. In the most southerly part of our zone the surrounding rocks are represented by *biotite paragneisses* including lenses and beds of limestones and calciphyres.

The tonalitic-gabbrodioritic mass.

The rocks which form the plutonic mass of the right side of the Shigar valley differ in composition and petrographic characteristics. In fact there is represented, with varying frequency, the whole series between the leucogranites and the amphibolic gabbros. The variations from one type to another can also occur rapidly, but, on the whole, two portions of the mass are distinguishable; one is characterised by the absolute prevalence of *tonalites*, the other of *diorite* and *gabbrodiorite*.

In the northern part of the valley, between Tisar and Korite, the *tonalitic types* completely predominate. In this part of the valley these show a greater constancy of composition than the rocks of the basic zone. The main differences are due to the differing intensity with which they have been affected by the epimetamorphic transformations.

The fresh rocks correspond to *cataclastic tonalites* (54 PZ-130; 54 PZ-264) and are always greenish in colour. They are characterized by the abundance and idiomorphism of the *plagioclases* (oligoclase-andesine 25-32% An) (1), by the disposition of patches of femic minerals (*amphibole* and *biotite*), and by

(1) The variation of composition is due to zoning. At some points higher percentages have also been measured, about 40% An.

the interstitial position of *quartz* (Plate 15, fig. 1). The twinned plagioclases are always partially altered to sericite and epidote and much more intensely so at points where the dynamic action has been stronger. Generally only the peripheral, more sodic (albite-oligoclase 8-15% An) parts of the plagioclasic crystals are fresh (1). Biotite and chlorite are recrystalized in the fractures of the plagioclases.

Other plagioclases, on the whole similar in composition to the peripheral parts of the former but varying from place to place, are irregularly twinned and form ill-defined patches, which include particles of all the other mineralogical components and, especially, deeply replaced portions of more calcic plagioclase. Around these sodic patches, the sodic borders of the idiomorphic plagioclases are more developed than elsewhere (Plate 15, fig. 2).

The main mafic mineral, *green hornblende*, is often altered into *biotite*, *epidote*, *chlorite* and, sometimes, *actinolite*.

Rocks of this type sometimes have fine, compact, greener bands, corresponding to zones of more intense lamination and mylonisis. When the dynamic actions have affected the whole rocks *tonalitic cataclasites* (54 PZ-131) or *tonalitic mylonites* (54 PZ-132) are formed. In these the plagioclase is totally or almost totally altered into a *sericitic-epidotic aggregate*, the mafic minerals into *chlorite* and *epidote*, and the quartz is reduced to very fine granules. In this fine more or less schistose matrix, there can be enclosed large granular particles of *quartz* (with ondulose extinction) and patches of *chlorite*, inside which the relics of amphibole are sometimes still recognizable.

The low content in An shown by the plagioclases of these tonalites is due in part to the transformation into sericite and epidote caused by a process of diaphtoresys concomitant with the dynamometamorphic action (metamorphic split). The more sodic plagioclases (albite-oligoclase), i. e. the irregularly twinned particles which form indefinite patches, and the peripheral portions of the larger particles, crystallized later.

Chemical analysis was made on one of the less cataclastic facies (54 PZ-130). The analytical and petrochemical data given in Table 18 show that this rock corresponds perfectly with the *normal quartz dioritic* type of the *quartz dioritic* magmas.

From Korite to the southern contact zone south of Nielle and from the

(1) The variation of composition by zoning between the sodic marginal parts and the calcic central parts is continuous (as can be seen by the gradual variation of the extinction angle of albite twins in the zone ⊥ (010)). The presence of mixtures with content in An higher and lower to 20% is clearly shown by the inversion of sign of the extinction angle.

TABLE 18

Cataclastic tonalite; *near Tisar* (54 PZ-130).

CHEMICAL COMPOSITION

(Analyst: B. Zanettin)

SiO_2	61.28%	MgO	2.51
TiO_2	0.66	CaO	5.52
P_2O_5	0.17	Na_2O	4.01
Al_2O_3	16.26	K_2O	1.72
Fe_2O_3	2.07	H_2O+	1.17
FeO	4.85	H_2O-	0.16
MnO	0.18		
			100.56

NIGGLI'S values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Tonalite from Tisar	204.7	32.0	31.7	19.7	16.6	0.22	0.39	0.62
Normal quartz dioritic type	225	32	31	19	18	0.25	0.45	

Basis				*Molecular Norm*	
Q	43.3	Q	= 43.3	Q	13.0
Kp	6.2	L	= 41.0	Or	10.4
Ne	21.9	M	= 14.9	Ab	36.6
Cal	12.9	M′	= 15.7	An	21.5
Cs	1.5	π	= 0.31	Wo	2.0
Fs	2.2	μ	= 0.36	En	7.1
Fo	5.3	γ	= 0.10	Hy	6.4
Fa	5.9	α	= 3.05	Mt	2.2
Ru	0.5			Ru	0.5
Cp	0.3			Cp	0.3

valley bottom to remarkable heights, rocks of definitely basic type — *diorites, gabbrodiorites and gabbros* — showing variations of composition and grain, occur.

This belt of femic rocks coincides (see preceding paragraph) with the zone characterized by the occurrence of sometimes abundant fragments of pelitic schists, limestones and calciphyres. It begins exactly in that part of the valley between Korite and Chundupon where interbedded limestones and calc-schists form a large inclusion in the plutonic rocks.

A *microdiorite* (54 PZ-270) from near Chundupon shows irregular lighter and darker patches. The femic minerals are represented by *green hornblende* and *epidote*, accompanied by a little *biotite*. The *plagioclases*, tending to idiomorphism, have a somewhat sodic composition (10-15% An) (1) and in some cases include muscovite and epidote, and very rarely biotite and hornblende. Also present are small quantities of *quartz* and, inside the ill-defined aggregates of sialic minerals, small quantities of *potash-feldspar*. The more common accessory minerals are *apatite* and *sphene*.

Rocks with well developed amphibolic crystals have also been observed.

In the zone between Matulu and Pendo, on the whole, more basic rocks prevail; they are often formed by lighter and darker portions.

Gabbrodiorites (54 PZ-274) and *microgabbrodiorites* (54 PZ-276) are formed mainly of *hornblende*, and smaller quantities of *biotite* and *plagioclases* 35% An (2). These sometimes (54 PZ-276) have a suborientated disposition, resembling the texture of some norites of the Indus valley (Twar zone). The plagioclases can be (54 PZ-274) greatly altered into sericite and epidote in the central parts and sometimes include in the outer parts biotite and amphibole, which show no traces of transformation.

The quartz can be absent (54 PZ-276), or abundant (54 PZ-274), according to the locality.

Also slightly different in composition is *gabbrodiorite* (54 PZ-277) found between Pendo and Bhundo but it is distinguished from the others by the poikilitic appearance often shown by the amphiboles as a consequence of reciprocal inclusions with the plagioclase, by which they are sometimes partially substituted. Furthermore the plagioclases, corresponding to andesine 40% An, often have a considerably more calcic core (55-70% An) (3). (Plate 15, fig. 3).

The chemical analysis given in Table 19 enables one to classify this latter rock (54 PZ-277) among the *gabbrodioritic magmas*, or as a transitional type between the *normal gabbrodioritic type* and the *orbitic type* of the group of *dioritic magmas*.

Inside these diorites and gabbrodiorites numerous bands of calciphyres, sometimes almost completely amphibolic, are enclosed (54 PZ-275). Some indefinite streaks of sialic rocks are also visible. Between Pendo and Bhundo the basic rocks maintain the same characteristics, but here and there leucocratic patches of granitic or tonalitic appearance also occur.

(1) $\gamma' < \omega_q$; positive optic sign; the maximum extinction angle of albite twins measured in the zone $\perp$ (010) = 8^0-10^0 = 10-13% An.

(2) $\gamma' = \varepsilon_q$; the maximum extinction angle of albite twins measured in the zone $\perp$ (010) = = 18^0 = 35% An.

(3) The determinations have been made in albite and albite-Carlsbad twins.

TABLE 19

Gabbrodiorite; *between Pendo and Bhundo* (54 PZ-277).

CHEMICAL COMPOSITION

(Analyst: E. Callegari)

SiO_2	50.03%	MgO	5.09
TiO_2	1.58	CaO	9.42
P_2O_5	0.28	Na_2O	2.92
Al_2O_3	16.50	K_2O	1.09
Fe_2O_3	3.54	H_2O+	2.12
FeO	6.95	H_2O-	0.12
MnO	0.14		
			99.78

NIGGLI'S values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Gabbrodiorite from Bhundo	126.6	24.6	41.0	25.5	8.9	0.20	0.47	0.62
Normal gabbrodioritic type	130	23	44	22.5	10.5	0.2	0.5	
Orbitic type (dioritic magmas)	135	27	42	21.5	9.5	0.25	0.5	

Basis				*Molecular Norm*	
Q	31.9	Q	= 31.9	Q	0.8
Kp	4.0	L	= 38.2	Or	6.7
Ne	16.3	M	= 28.2	Ab	27.2
Cal	17.9	M′	= 29.9	An	29.8
Cs	5.1	π	= 0.47	Wo	6.8
Fs	3.8	μ	= 0.39	En	14.5
Fo	10.9	γ	= 0.18	Hy	8.7
Fa	8.4	α	= 0.64	Mt	3.8
Ru	1.1			Ru	1.1
Cp	0.6			Cp	0.6

South of Nielle the femic rocks are literally full of small inclusions of calciphyres. The samples taken opposite Shigar correspond to *diorites* (54-Z 281, 281 a) and their textural and mineralogical features reveal their endometamorphic origin.

They are fine-grained amphibolic rocks enclosing greenish patches, evidently rich in epidote.

The dioritic portion is formed with small particles of *andesine* 45% An (1) and greenish blue *hornblende* in elongated particles, which are better developed and very poikilitic (Plate 15, fig. 4). Near the contact with the enclosed cal-

(1) The maximum extinction angle of albite twins measured in the zone ⊥ (010) = 25°-28° = 45-50% An.

ciphyres the amphibole loses its pleochroism and at the same time becomes associated with *epidote*, sphene and sometimes *calcite*. In places where rocks of dioritic type forms tongues inside the calciphyres, a *pyroxene* of diopsidic or diopsidic-fassaitic type also appears.

The calciphyre is formed of *epidote* and *pyroxene*, with variable quantities of *sphene*, *calcite*, *garnet*. Large irregular patches of *quartz* are often present.

Diorites and gabbrodiorites in small masses or in spots also appear on the southern side of mount Marshakala, inside the surrounding schists.

The sialic gneissic marginal belt of the pluton.

On the upper margin of the tonalite-gabbrodiorite pluton there is a long belt of sialic rocks consisting of *plagioclase gneisses* and *granitic gneisses* having more or less evident gneissic texture; they acquire, gradually, a more massive texture and could be indicated as *gneissic granite*.

This belt, of irregular thickness but almost continuous, is exposed along the Shigar valley at a somewhat high altitude and passes through the divide of Shigar-Indus, north-west of the mount Marshakala.

In the alluvium of the torrent which enters near Kaiyu I have collected a sample resembling a porphyritic granite including dark patches, like "schlieren", in which, as in the remaining part of the rock, large feldspathic crystals stand out. This rock, defined as being of *plagioclase gneiss* with porphyroblastic texture (54 PZ-266) is formed mainly of oligoclase occurring sometimes as large isolated crystals, sometimes as patches, with many zones (1), including small crystals of epidote and sericite; they are without distinct crystalline limits, and tend to idiomorphism. In the interstices of the plagioclasic porphyroblasts there are other minerals, with a medium grain size, consisting of joined particles of *quartz*, of crystalloblasts of *biotite* and of smaller quantities of *hornblende* and *epidote*. The mafic minerals are inclined to combine into patches.

In the peripheral parts of the large plagioclasic crystals, and in some smaller particles, biotite can be included together with hornblende (partially altered to epidote) and large granules of epidote (Plate 17, fig. 3). It seems that the peripheral parts of some plagioclases have been formed successively to the dynamic actions that have acted on this rock.

(1) $\varepsilon_q > \gamma' > \omega_q$; optic sign always negative. No precise measurements were possible, but the various mixtures show composition between 20% and 25% An.

Also from the same locality comes a *plagioclase gneiss rich in epidote* (54 PZ-268) and having the appearance of a cataclastic granite. The *plagioclase*, corresponding to *albite-oligoclase* 8-15% An (1), definitely represents the most common mineral. They form well developed idioblasts including many poikiloblasts of *muscovite* and *epidote*, which are for the most part orientated inside the host, and also, very occasionally, *amphibole* (Plate 17, fig. 4).

TABLE 20

Leucogranitic mylonitic gneiss; *between Kaiyu and Yonskil* (54 PZ-269).

CHEMICAL COMPOSITION

(Analyst: B. Zanettin)

SiO_2	72.21%	MgO	0.38
TiO_2	0.13	CaO	1.78
P_2O_5	0.06	Na_2O	4.42
Al_2O_3	15.65	K_2O	3.62
Fe_2O_3	0.32	H_2O+	0.95
FeO	0.79	H_2O-	0.14
MnO	0.10		
			100.55

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Leucogranitic gneiss from Yonskil	374.9	47.9	8.0	9.9	34.2	0.35	0.36	1.23
Aplite-granitic type (leucogranitic magmas)	460	47	8	5	40	0.45	0.25	
Yosemiteaplitic type (leucogranitic magmas)	350	45	6	13	36	0.4	0.3	

Basis				*Molecular Norm*	
Q	54.6	Q	= 54.6	Q	24.8
Kp	12.9	L	= 41.9	Or	21.5
Ne	23.9	M	= 3.3	Ab	39.8
Cal	5.1	M′	= 3.5	An	8.5
Sp	1.6	π	= 0.12	Hy	0.7
Hz	0.7	μ	= —	Cord	2.9
Fs	0.3	γ	= —	Fe-Cord	1.3
Fa	0.7	α	= 22.85	Mt	0.3
Ru	0.1			Ru	0.1
Cp	0.1			Cp	0.1

(1) $\gamma' < \omega_q$; optic sign always positive; the maximum extinction angle of albite twins measured in the zone ⊥ (010) = 11°-12° = 8% An. There are also portions of the crystals having an extinction angle of 7°-8° = 13-14% An.

(2) $\gamma' < \omega_q$; positive optic sign; the maximum extinction angle of albite twins measured in the zone ⊥ (010) = 8°-10° = 10-14% An.

The interstices between the crystals of plagioclase are filled by large joined granules of *quartz* and by patches of *epidote*, *biotite* and *chlorite*, often accompanied by *sphene* and *actinolite*.

A *granitic blastomylonitic gneiss* (54 PZ-269) has been collected in the scree in that part of the valley between Kaiyu and Yonskil. It has a fine matrix, formed of *quartz*, *biotite*, *muscovite* and *epidote*, with a blastomylonitic texture. Prominent on this mylonitic matrix are porphyroblasts of *albite-oligoclase* (2) and of *potash-feldspar* (generally *microcline*) (Plate 18, fig. 1) with the fractures completely healed, and often coated by very fine feldspathic or quartzose-feldspathic aggregate, inside which biotite, muscovite and epidote can also be found. The plagioclases generally include a certain quantity of muscovite and epidote, and rarely, but only in the peripheral part, biotite. The *potash-feldspar* includes small plagioclases and granules of quartz.

Myrmekite is formed, locally, at the boundary between the two types of feldspar (Plate 18, fig. 3).

TABLE 21

Leucogranitic gneiss; *between Pendo and Bhundo* (54 PZ-268).

CHEMICAL COMPOSITION

(Analyst: E. Callegari)

SiO_2	72.66%	MgO	0.76
TiO_2	0.28	CaO	1.84
P_2O_5	0.11	Na_2O	3.88
Al_2O_3	14.40	K_2O	3.68
Fe_2O_3	0.57	H_2O+	0.68
FeO	1.46	H_2O-	0.16
MnO	0.08		
			100.56

NIGGLI's values

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*	*c/fm*
Leucogranitic gneiss from Pendo	374.2	43.7	14.7	10.1	31.5	0.38	0.40	0.69
Yosemite-granitic type (leucogranitic magmas)	350	43	14	13	30	0.45	0.30	

Basis				*Molecular Norm*	
Q	55.4	Q	= 55.4	Q	27.3
Kp	13.2	L	= 39.4	Or	22.0
Ne	21.1	M	= 4.8	Ab	35.2
Cal	5.1	M′	= 5.2	An	8.5
Sp	1.6	π	= 0.13	En	1.1
Fs	0.6	μ	= 0.17	Hy	2.0
Fo	0.8	γ	= —	Cord	2.9
Fa	1.8	α	= 16.81	Mt	0.6
Ru	0.2			Ru	0.2
Cp	0.2			Cp	0.2

A chemical analysis was made on this granitic gneiss. Study of the analytical data shown in the Table 20 shows that the rock corresponds chemically to the group of *leucogranitic magmas* (the aplite-granitic and the yosemite-aplitic types).

In the alluvium between Pendo and Bhundo, that is, in the zone where rocks of dioritic type predominate, gneissic *granites* and *leucogranites* (54 PZ-278) also occur; one of these, with crystalloblasts of *biotite*, *muscovite* and occasionally *epidote*, is formed essentially of *quartz*, *albite-oligoclase* 10-15% An (1) and *microcline* and has a texture little different from that of the pegmatites.

Large particles of *quartz* occupy extensive patches, in which feldspars are sometimes included.

Plagioclases and *microcline* form porphyroblasts, nearly always without definite shapes, which, when they come in contact, give way to large patches of *myrmekite*. The former include poikiloblasts of muscovite and sometimes flakes of *biotite*, whose peripheral parts lose their pleochroism giving way to poikiloblasts with the appearance of muscovite (Plate 18, fig. 4). Inclusions of quartz and calcite are rare. The microcline encloses many small plagioclasic particles (Plate 18, fig. 2).

A chemical analysis has also been made of this gneissic granite (Table 21). The values of the magmatic formulas show that this rock also falls into the group of *leucogranitic magmas* showing close analogies with the *yosemite-granitic type*.

The *dykes*, always of sialic type, have been observed only in the southern part of the Shigar valley, south of Nielle, and discordantly cross both the basic rocks and the surrounding formations. They are for the most part subvertical dykes, sometimes of great thickness (several metres thick and many hundreds of metres long).

The rock of a dyke of modest thickness when examined under the microscope is seen to have a granitic composition (54 PZ-282) and shows a definite gneissic appearance as a consequence of blastesys occurring subsequent to dynamic actions. It has a fine grain and is formed essentially of quartz, plagioclase 10-15% An and *microcline*. This last mineral seems to have replaced the plagioclase at some point, and often encloses roundish grains of quartz.

From what has been said it can be seen that this somewhat complex plutonic mass shows a certain continuity in the northern part of the outcrops,

(1) $\gamma' < \omega_q$; positive optic sign; the maximum extinction angle of albite twins measured in the zone ⊥ (010) = 8°-10° = 10-14% An.

while the southern basic zone, because of the great abundance of surrounding rocks enclosed in it, could be considered as an agmatitic zone. Eventually the mass splits up into small masses, pockets and patches, inside the surrounding rocks.

This discontinuous character must be maintained over a remarkably large area (now partially buried by the alluvium of the Shigar and Indus rivers), at least judging from the rapid observations made on the left side of the lower Shigar valley, between the small lake Yarba (Yarba Tso) and Skardu.

Near Yarba Tso some biotite schists with many quartzose lenses are crossed by dykes and small veins of granitic type. In the direction of Skardu patches of sialic and femic rocks of very unstable composition begin to appear, passing one into the other. Farther south they become predominant and enclose large fragments of biotitic schists.

CONCLUSIONS

CHEMICAL VALUES

As it has been said in the paragraph on geological conditions, the various fundamental facies which form the pluton of the Shigar valley are distributed in such a way that each one of them predominates in a certain portion of the mass. The values obtained from the chemical analysis of these are combined in Table 22.

The more common facies, indeed almost the exclusive one, in the central and northern parts of the valley, corresponds, from the chemical point of view, to a *quartz diorite* (*normal quartz dioritic type*).

It must be remembered that the composition of this rock is nearly the same as that of a facies representing a common sialic differentiation of the dioritic-noritic mass of Twar. Niggli's values show differences of little importance except in the value *k*, which is 0,22 for the tonalite of Shigar and 0,32 for the quartz diorite of Twar. As previously mentioned the quartz diorite of Twar has been interpreted as the product of a reaction between the originally more basic rocks and materials of siliceous and potassic composition introduced into it. The almost perfect chemical analogy between the quartz diorites of Twar and those of Shigar does not, however, indicate a genetic relation, because the two masses show very different petrographic features.

The representative facies of the femic rocks which occur largely in the southern part of the mass correspond to *normal gabbrodioritic* types with a certain tendency towards the *orbitic* type of the *dioritic magmas.* It is rich in calcium, so that the coefficient *c* has higher values than those characteristic of the magmatic types among which it is placed.

As it has been mentioned, along the margin of the plutonic body under discussion there is a long sialic belt, whose southern portion consists of granitic gneisses, which gradually change into gneissic granites.

In order to determine the composition of these granitic gneisses, two samples of different texture and taken far apart, were chosen. One (granitic gneiss) was taken between Kaiyu and Yonskil, the other (gneissic granite) between Pendo and Bhundo. The analytical data and the magmatic formulas show that sensible chemical differences do not exist between the two samples. Both fall into the group of the *leucogranitic magmas*, the first approximating to the *aplite-granitic* and *yosemite-aplitic* types, the second to the *yosemite-granitic* type.

In order to establish a comparison between our rocks and the rocks which form the large pluton occurring over the greater part of southern Baltistan, the chemical analysis and the magmatic formulas relating to these rocks are shown in Table 22.

The author does not intend to compare in detail the analytical data in order to show the analogies and the differences of composition between the rocks analysed. It is more important to stress the fact that both at Shigar valley and at the southern part of Baltistan, sialic rocks of *leucogranitic type* are present in close association with more femic ones: *tonalites, diorites, gabbrodiorites* and *gabbros*, whilst absent are rocks with intermediate composition corresponding to the granitic and granodioritic magma groups of NIGGLI's classification.

On the whole, it can be said that a general similarity of composition exists between the rocks of the Shigar valley mass and those of the granitic-dioritic pluton of southern Baltistan.

Finally, I will repeat that in the outcrop of this latter pluton there have been collected and analysed rocks analogous to the plagioclase gneisses of the Shigar valley which I did not analyse because of their petrographical similarity to the plagioclase gneisses of Skoyo-Turmik.

These plagioclase gneisses show exceptionally low values of *k* as do some plagioclase gneisses of Skoyo-Turmik, and are thus referred, although not corresponding very well to it, to the group of trondhjemitic magmas (P. COMUCCI, 1938, page 115).

TABLE 22

GRANITIC-DIORITIC MASS OF THE LEFT SIDE OF THE SHIGAR VALLEY.

ANALYSED ROCKS

Locality	Petrographic classsification	Chemical classification according to Niggli's magmatic types
1. - The Lower Basha valley, in the small valley to the west of Tisar.	Cataclastic tonalite (54 PZ-130).	*Normal quartz dioritic type.*
2. - The Shigar valley, between Pendo and Bhundo.	Amphibolic gabbrodiorite (54 PZ-277).	Between the *normal gabbrodioritic type* and the *orbitic type* of the dioritic magmas.
3. - The Shigar valley, between Kaiyu and Yonskil.	Granitic mylonitic gneiss (54 PZ-269).	Leucogranitic magmas: between the *granite-aplitic* and the *yosemite-aplitic type.*
4. - The Shigar valley, between Pendo and Bhundo.	Granitic gneiss with pegmatitic texture (54 PZ-278).	*Yosemite-granitic type.*

ROCKS FROM THE SOUTHERN BALTISTAN

5. - The Tolti valley, on the right side of the Indus valley (collected by G. DAINELLI).	Cataclastic granite (P. ALOISI, 1932, pag. 15).	*Yosemitic type.*
6. - The Indus valley, near Shiriting (collected by G. DAINELLI).	Amphibole-biotite quartz-diorite (P. ALOISI, 1932, pag. 67).	Leucogabbroic magmas: *leucomiharaitic type.*
7. - The Tolti valley, on the right side of the Indus valley (collected by G. DAINELLI).	Amphibole-biotite quartz-diorite (P. ALOISI, 1932, pag. 69).	Between the *miharaitic type* of the gabbroic magmas and the *normal gabbrodioritic type.*

(TABLE 22 - Continued)

CHEMICAL COMPOSITION

ANALYSED ROCKS

	1 Analyst: B. Zanettin	2 Analyst: E. Callegari	3 Analyst: B. Zanettin	4 Analyst: E. Callegari
SiO_2	61.28%	50.03%	72.21%	72.66%
TiO_2	0.66	1.58	0.13	0.28
P_2O_5	0.17	0.28	0.06	0.11
Al_2O_3	16.26	16.50	15.65	14.40
Fe_2O_3	2.07	3.54	0.32	0.57
FeO	4.85	6.95	0.79	1.46
MnO	0.18	0.14	0.10	0.08
MgO	2.51	5.09	0.38	0.76
CaO	5.52	9.42	1.78	1.84
Na_2O	4.01	2.92	4.42	3.88
K_2O	1.72	1.09	3.62	3.68
H_2O+	1.17	2.12	0.95	0.68
H_2O-	0.16	0.12	0.14	0.16
	100.56	99.78	100.55	100.56

ROCKS FROM THE SOUTHERN BALTISTAN

	5 Analyst: Casati	6 Analyst: Lopez	7 Analyst: Casati
SiO_2	71.14%	55.39%	52.66%
TiO_2	tr.	1.31	1.20
P_2O_5	0.07	n.d.	0.12
Al_2O_3	15.12	15.50	14.06
Fe_2O_3	0.66	5.62	6.68
FeO	1.44	3.04	5.75
MnO	tr.	n.d.	0.22
MgO	0.37	4.52	4.01
CaO	2.88	9.55	9.06
Na_2O	3.46	3.99	2.66
K_2O	3.97	0.49	1.08
H_2O+	0.90	0.78	2.28
H_2O-		0.18	
	100.01	100.37	99.78

NIGGLI'S values

Analysed rocks	*si*	*al*	*fm*	*c*	*alk*	*k*	*mg*
1. Tonalite from Tisar	204.7	32.0	31.7	19.7	16.6	0.22	0.39
2. Gabbrodiorite from Pendo	126.6	24.6	41.0	25.5	8.9	0.20	0.47
3. Granitic gneiss from Kaiyu	374.9	47.9	8.0	9.9	34.2	0.35	0.36
4. Granitic gneiss from Pendo	374.2	43.7	14.7	10.1	31.5	0.38	0.40

(TABLE 22 - Continued)

Rocks from southern Baltistan	*si*	*al*	*fm*	*c*	*alk*	*k*	*mg*
5. Granite from Tolti	353.86	44.23	11.16	15.34	29.27	0.43	0.24
6. Diorite from Shiriting	149.53	24.62	36.50	27.61	11.27	0.07	0.50
7. Gabbrodiorite from Tolti	141.40	22.20	42.96	26.07	8.77	0.21	0.37
NIGGLI'S *magmatic types*							
Quartz dioritic magmas:							
Normal quartz dioritic type	225	32	31	19	18	0.25	0.45
Dioritic magmas:							
Orbitic type	135	27	42	21.5	9.5	0.25	0.5
Gabbrodioritic magmas:							
Normal gabbrodioritic type	130	23	44	22.5	10.5	0.2	0.5
Gabbroic magmas:							
Miharaitic type	130	23	42	27.5	7.5	0.2	0.5
Leucogabbroic magmas:							
Leucomiharaitic type	140	26.5	38	26.5	9	0.25	0.45
Leucogranitic magmas:							
Aplite-granitic type	460	47	8	5	40	0.45	0.25
Yosemite-aplitic type	350	45	6	13	36	0.4	0.3
Yosemite-granitic type	350	43	14	13	30	0.45	0.30

ANALOGIES WITH OTHER HIMALAYAN FORMATIONS

G. DAINELLI maintains that the granitic-dioritic rocks occurring on the right side of the Shigar valley are similar to those of the large granitic-dioritic mass which occupies a large part of central Baltistan, "from the basin of Dras to the basin of Skardu along the Indus river, and to that of Kapalu along the Shyok". Moreover, the geological and petrographic analogies are such that the dioritic-granitic rocks of the Shigar valley almost certainly represent the most northerly manifestations of the intrusive activity which brought this large mass into existence.

I shall not summarise G. DAINELLI's ideas about the succession of igneous processes which have affected central Baltistan and about the relations observed among the different rocks derived from them. It will be sufficient to recall that this author thinks that the intrusive activity which resulted in the large granitic-dioritic masses, is genetically related to the prevailingly volcanic basic manifestations observed by him in the basin of Dras and along the valley of the Ladakh Indus. According to this author the intrusive activity should have, generally, preceded the extrusive one of the Upper Cretaceous (Senonian) and it also should have developed in the Upper Cretaceous (G. DAINELLI, 1934, page 745) or, at any rate, not later than the Senonian (Ibid.; page 662).

According to G. DAINELLI, diorites and granites, often inter-penetrated so as to make one think that the rocks have been formed by "two different and coeval magmas, complicatedly mixed together" (ibid., page 646), are generally, in contact with schistose rocks of pre-Silurian age. "Only in one case" (in the lower Dras valley) "is there actual topographic, and probably also original, proximity, and there is also a phenomenological transition between a large dioritic mass on one side and the extrusions which occurred during the Senonian on the other" (ibid., page 661). The surrounding rocks are often enclosed within the intrusive rocks and are sometimes irregularly "replaced" by these, "so that small bands of schists, although maintaining their normal strike, are isolated in the granite" (ibid., page 697). This latter feature represents, in my opinion, another interesting point of similarity between the Shigar valley mass and the large pluton which extends south of Skardu.

The petrographic study of the surrounding rocks (P. ALOISI, 1933, pages 241, 258-259) has shown that only rarely they have been affected by thermal metamorphism, "while it is very clear and strong at the contact with the dykes" which "are presumably later, than... the large masses of intrusive rocks".

This last fact is in contrast with what I have observed in the Shigar valley, where many bands of sedimentary rocks of different nature (argillaceous, argillaceous-arenaceous, calcareous-argillaceous and calcareous) enclosed in dioritic and gabbrodioritic rocks show mineralogical associations undoubtedly resulting from thermal metamorphism.

With reference to the two fundamental types of rock which form the plutonic mass of southern Baltistan — the granites and diorites — P. ALOISI observes that the granites generally contain small quantities of potash-feldspar and are thus, rather than real granites, transitional types to the quartziferous diorites. On the other hand the diorites are somewhat acid quartziferous types, which, because of the occasional presence of potash-feldspar, are transitional types towards the granites.

Other extensive outcrops of igneous rocks, classified generically as "hornblende granite", were observed by D. N. WADIA (D. N. WADIA, 1937) in the zone south of Astor (east of Nanga Parbat). These continue from Chechri Kadal, through the Burzil Pass, to the Dras zone, i. e. to a zone which had already been mapped by G. DAINELLI. They therefore represent the most westerly parts of the large plutonic mass of central Baltistan and are in contact with the rocks of the volcanic-sedimentary series, also attributed by D. N. WADIA to Cretaceous. This, therefore, suggests that the rocks under discussion should be Eocene or post-Eocene (D. N. WADIA, 1937, page 159).

About the relationships between the intrusive acid rocks and the volcanic rocks he says (D. N. WADIA, 1937, page 154):

"The entire north-east margin of the volcanic belt is in intrusive contact with hornblende granite (a white or grey, fine-grained feldspathic granite, with only small amounts of hornblende) along a high indented line, full of bays and tongues". And later (ibid., page 158); "A boss of hornblende granite... has detached from the main body of the outcrop a strip of shaly tuffs, with limestone intercalations, which is about a mile wide; other smaller detached masses occur as islands in the granite".

Other large hornblende granite masses all classified as of Cretaceous or Cretaceous-Eocene age are found in the zones of Gilgit and Hunza (C. A. McMAHON, 1900), (i. e., west of the large migmatitic formation that occurs in the belt joining the groups of Nanga Parbat and Haramosh) and farther away, in the valleys of the Brahamaputra and in the Tibetan high-lands, around Lhasa.

G. DAINELLI, who has made a comparative study of these masses, considers all these plutonic masses as the manifestations of a single great magmatic cycle. Referring to the large diffusion of "micaceous-amphibolic granite" in the Himalayan chain (and in Afghanistan), he proposed to call it "Tibetan granite" or, more generically, "Trans-Himalayan granite" as opposed to "Himalayan granite".

The granitic-dioritic mass of the Shigar valley, undoubtedly is *post-Cretaceous*, because it is in contact with, and encloses rocks (amphibolites etc.) which represent the metamorphic equivalent of the volcanic-sedimentary series of Senonian age occurring in the most southerly zones (see page 106, 107). The age and the geological situation of our granitic-dioritic mass ought therefore to be analogous to that indicated by D. N. WADIA for the masses of hornblende granite in the Astor-Burzil-Dras zone.

PETROGENESIS

The observations made in the field and study in the laboratory show that the rocks forming the right side of the Shigar valley have very variable petrographic and chemical characteristics. Furthermore the transitions between the different facies of the granitic-dioritic mass and between these and the surrounding rocks are seldom abrupt. The variability of the lithological features and the complexity of the relationships between the different types of rock occurring on this side are, together with the scarcity of observations made in the field, the reasons why an exact and co-ordinated picture of the processes which have caused the genesis of formations cannot be given. The discussion of the petrogenetic processes will therefore be discontinuous and limited to those features most evident in the field.

The variability of the plutonic rocks must be, in my opinion, the consequence of several processes rather than of the intrusion of magmas of different original composition. The two main processes were, most probably, the assimilation of the surrounding rocks of calcareous or calcareous-argillaceous composition and the feldspathization of the surrounding rocks of amphibolitic type. The different nature of the surrounding rocks also explains the diversity of their metamorphic transformations by the granitic-dioritic mass.

THE TONALITES.

Of the rocks which form the post-Cretaceous mass on the right side of the Shigar valley — granites, tonalites, diorites and gabbrodiorites — the tonalites show a greater constancy of features and occur over a more extensive area. The uniformity of the tonalites would be even greater, if they had not been submitted to the dynamometamorphic actions which have caused epimetamorphic and structural transformations of very different intensity. To these actions, as I have already said, is attributed the splitting of the original plagioclase in very sodic members and in epidote.

Very little can, in fact, be said about the origin of these tonalites, because besides the scarcity of observations made in the field there is the added difficulty, caused by the late deformations of the rocks, of finding under the microscope features of definite petrogenetic significance. The following points seem to favour a *magmatic origin* of at least some of these tonalites:

the phenomenon of thermal metamorphism induced by them in the surrounding rocks; their probably original granular texture; their uniformity of composition; and, above all, the neat intrusive contact planes observed by D. N. WADIA and G. DAINELLI in central Baltistan, Ladakh and Astor, in masses similar to these.

After the deformations to which they have been submitted, these tonalites have undergone modifications by the introduction of small quantities of sodic material, which caused the formation of irregular patches of albitic-oligoclasic plagioclases, enclosing portions of all the other rock minerals, and replaced the peripheral portions of the pre-existing, more calcic plagioclase (Plate 15, figs. 1, 2).

The diorites and gabbrodiorites.

The basic rocks — *diorites*, *gabbrodiorites*, and sometimes *gabbros* — are localized in the southern portion of the mass, where the surrounding rocks are of calcareous, argillaceous and calcareous-argillaceous type and are often enclosed in the basic mass in the form of xenoliths, which have been deeply altered by contact metamorphism. Yet this coincidence seems to indicate that *there are relationships between the nature of the surrounding rocks and basicity of the intrusive rocks*, because analogous relationships have often been observed in many places throughout the world and in the same area of Karakorum mapped by me (Twar zone). This hypothesis is reinforced by the following facts:

— The fundamental femic mineral is always represented, even in the more basic types, by amphibole (never pyroxene), accompanied by variable quantities of biotite; that is, the mineralogical association is characteristic of dioritic-tonalitic rocks. The pyroxene is present only in the endometamorphic rocks nearest the contact.

— near calcareous inclusions (calc-silicate hornfelses) the amphibole becomes poikiloblastic, with light blue-green colours, and, ultimately colourless, while epidote and the sphene appear and become progressively more abundant (Plate 15, fig. 4);

— the plagioclase often has a more calcic core mainly replaced by a much more sodic plagioclase (Plate 15, fig. 3).

All these features have often been considered as *the product of the assimilation of calcareous rocks by magmas of more or less sialic composition.*

It is difficult to be precise about the real nature of the magma which has caused these phenomena of syntexis, because the final product of the process depends on the stage of differentiation reached by the magma at the moment when reactions with the surrounding rocks begin. The composition of the plagioclase (35-45% An) and of the femic minerals seem to indicate mesopersilic magmas.

Granitic gneisses and plagioclase gneisses.

The more sialic rocks occurring on the right side of the Shigar valley have a clearly metamorphic texture.

As regards their topographic distribution it has already been seen that they form the upper part of the granitic-dioritic mass, i. e. they form an almost continuous belt which overlies the tonalitic and dioritic outcrops. Furthermore, it is interesting to note the fact that in the northern part of this sialic belt are found only plagioclase gneisses, without potash-feldspar, while the granitic gneisses begin to appear only south of Kaiyu, as the direct continuation of the plagioclase gneisses.

The *plagioclase gneisses*, at least judging from the pebbles carried by the torrents, have a very variable composition. They are in fact formed of variously distributed light and dark patches. Generally the light portions, granitic in appearance, enclose the dark portions, which often have roundish forms. It is interesting to note that, both in the light and dark parts, the composition of the plagioclases, which assume remarkable dimensions and tend to form zoned idioblasts, is practically the same (10-20$^{0}/_{0}$ An). The plagioclases always enclose sericite and epidote in distinct crystals, but this does not seem to be attributable to epimetamorphic transformation because the plagioclases are always perfectly fresh. More probably they are the products enclosed in the course of the growth of the feldspathic porphyroblasts. The same explanation is also valid for the few more or less intensely transformed inclusions of biotite and hornblende. Concerning this latter mineral it may be remembered how it could also be enclosed in the plagioclase in rocks lacking hornblende and in which another type of amphibole, actinolite, is present only in small quantities (Plate 17, fig. 3).

Because of the similarity of composition and of character between the plagioclases present in the light and dark portions of the plagioclase gneisses, the difference between these two portions depends solely on the quantitative ratios between plagioclases, mafic minerals and quartz. In the light portions prevails, among the mafic minerals, the biotite accompanied by variable quantities of epidote and amphibole (which is sometimes so scarce as to be considered as a subordinate mineral). In the darker portions, however, hornblende is by far the most common mineral, accompanied by variable quantities of epidote and a little biotite.

A significant petrogenetic feature is shown by the fine-grained surrounding amphibolites gathered in that zone where plagioclase gneisses occur. They are irregularly mottled by a few poikiloblasts of albite-oligoclase plagioclase of obvious metasomatic origin, which enclose epidote, biotite and amphibole, comparable, in fact, to the porphyroblasts of the plagioclase gneisses (Plate 17, figs. 1, 2).

These factors give rise to the hypothesis that the *plagioclase gneisses were formed by the introduction of sialic material into pre-existing amphibolitic or* *epidote-anphibolitic rocks (the surrounding amphibolites). They would have undergone radical transformation by the crystallization of sodic plagioclases and of quartz, and by the biotitization of the original mafic minerals.*

It should be remembered that almost similar phenomena are to be expected (BOWEN, 1956, page 197) at the contact between sialic magmas and basic rocks, such as the present amphibolites.

It is therefore probable that amphibolites with feldspathic porphyroblasts and plagioclase gneisses are the product of a sodic metasomatism caused by the proximity of magmatic masses (1).

Observations on the *granitic and leucogranitic gneisses* are too scarce for any hypothesis about their genesis to be made. As regards the petrographic features visible under the microscope it is sufficient to remember:

— that these granitic gneisses often have a texture similar to that of the pegmatitic rocks (especially in the great abundance of myrmekites) (Plate 18, fig. 3);

— that both the plagioclase (10-15% An) and the K-feldspar can include poikiloblasts of muscovite and biotite. The latter progressively loses its colour by the removal of Fe^{++} (and maybe Mg) ions, and assumes the appearance and physical features of muscovite (Plate 18, fig. 4);

— that the microcline is found to have been formed successively to the crystallization of the other minerals because generally it encloses greater or lesser quantities of them in the form of small particles (Plate 18, figs. 1, 2).

The structural features and the relations observed on the field between granitic gneisses, plagioclase gneisses and the underlying intrusive mass, give the possibility to formulate the hypothesis that *the granitic gneisses of the Shigar valley are formed by reaction and replacement caused by potash- and silica-rich solutions on the pre-existing plagioclase gneisses. Our granitic gneisses would represent, therefore, the final product of a complex metasomatic process manifested on the roof of the big granite-dioritic batholith.*

A favourable reason for the existence of an autonomous potassic phase during the process of granitization of the host rocks is given by the presence of some biotite-labradorite gneisses. These rocks which lack any trace of preceding sodic metasomatic actions, show that they were affected by potash metasomatism, which caused the appearance, in remarkable quantity, of microcline metacrysts.

(1) The same origin could apply to the plagioclase gneisses occurring in the zone of Skoyo-Turmik, wich, as it has been said before, could represent the extreme results of the sodic metasomatism linked to the large intrusions of hornblende granite (or granitic-dioritic) of the central Baltistan

To complete the picture of the transformations caused by the plutonic mass of the Shigar valley by the introduction of sialic material into the surrounding rocks it should be recalled what I have already described (pages 87-88) about the rocks occurring between Gurbidas and Burum, in that portion of the Indus valley which runs parallel to the Shigar valley, quite near the outcrops of the granitic-dioritic mass. Here granitic and leucogranitic rocks, sometimes very rich in potash, and characterized by the presence of biotitic strips and patches, form outcrops with very irregular boundaries inside the surrounding amphibolites. These amphibolites, maintaining a constant trend, are enclosed in the granitic rocks as very numerous and often large patches, near which the enclosing rock often assumes the appearance of a microdiorite. Both the enclosed amphibolites and those that border these granitic outcrops are composed, in contrast to the amphibolites observed in other zones, of neatly zoned plagioclase.

Obviously this is an agmatitic zone where the original amphibolic rocks have been transformed in different ways by the introduction of sialic alkaline material and, maybe, mobilized. Particularly evident are the processes of biotitization.

I have already stated that in the northern part of the Shigar valley the plagioclase gneisses of the marginal belt and the surrounding amphibolites rich in plagioclasic porphyroblasts are practically devoid of potash-feldspar. The same situation is seen in the Turmik-Indus zone. The gneissic plagioclasic Skoyo-Turmik mass and the many dykes and veins of aplitic type which intersect the surrounding rocks are devoid of potash-feldspar, while south of the limestones of Tungas, rocks rich in potash-feldspar occur.

The rocks affected by thermal metamorphism.

Among the different metamorphic beds of the volcanic-sedimentary series occurring here, the argillaceous, calcareous and calcareous-argillaceous rocks prevailing in the southern right side of the Shigar valley have undergone transformations by thermal metamorphism, more or less intense, according to their nature and to their distance from the intrusive rocks.

Nearly all my observations were made on the large and small sized xenoliths enclosed in the diorites.

The argillaceous rocks can give way both to *spotted slates*, in which biotite and andalusite are found in an initial stage of crystallization (Plate 16, figs. 1, 2) and to *chlorite-biotite* schists with weak signs of metamorphism. However, the characteristic ***biotite-labradorite schists rich in garnet***, derived from impure argillaceous rocks, or from basic volcanic rocks deeply weathered, belong to the higher grades of metamorphism.

The mineralogical associations developed by thermal actions in the calcareous rocks are very varied. Leaving aside the pure limestones recrystallized into *marbles*, the limestones and dolomitic limestones containing variable quantities of impurities have given way to calciphyres and hornfelses with the following mineralogical associations: hornblende-epidote-pyroxene-sphene-(calcite); actinolite-hornblende-epidote; hornblende-pyroxene-sphene; wollastonite, diopside-epidote; epidote-pyroxene-garnet-sphene.

The calcareous rocks generally appear to be much more altered than the pelitic rocks, even when they are thinly interbedded with them or when the calcariferous material forms lenses enclosed in the argillaceous material. This is due to the greater speed of the reactions in the presence of CO_2, which gradually increases as a result of the reactions between the carbonates and the impurities contained in them. The result is a more rapid adjustment of the carbonatic rocks to the metamorphic conditions to which they are submitted.

A clear demonstration of this fact is observable in a sample (54-PZ 279) gathered by me, in which a calcareous lens, transformed into calciphyres rich in wollastonite, diopside and epidote, is enclosed in a biotitic schist. As a result of CO_2 developed in it, the minerals of the biotitic schist (biotite and quartz) near the calcareous lens have assumed dimensions decidedly greater than in the remaining parts of the rock (Plate 16, fig. 4).

In the surrounding amphibolites there is naturally no sign of thermal metamorphism, since these are formed by minerals higher in the Bowen's reaction series than those of the plutonic rocks that come in contact with them. As has been seen, the action of the tonalitic rocks has been developed on the amphibolites causing their feldspathization or incomplete granitization in the contact zone.

There is then, in this part of the Shigar valley, a good example of the different behaviour of the various types of surrounding rocks to the actions of the plutonic masses. The calcareous and calcareous-argillaceous rocks undergo radical transformations of their original mineralogical composition by thermal metamorphism (without excluding a certain supply of material) or can eventually be totally assimilated by the magma injected into them. The amphibolites, however, undergo transformations of metasomatic type.

It is not to be denied, however, that the appearance of feldspar of metamorphic origin has been preceded, in the amphibolites, by a general recrystallization equivalent to an increase of metamorphic grade.

In fact I think that it is more than coincidence that the schistose rocks of the volcanic-sedimentary series occurring between the Twar zone and the Shigar valley correspond to a higher grade (*mesozone* of GRUBENMANN; *amphibolite facies* of ESKOLA) in the areas affected by plutonic manifestations (intrusive masses, dykes, feldspathized zones) than in those lacking such manifestations (*epizone* of GRUBENMANN; *greenschist facies* of ESKOLA).

The constitution of the plutonic granitoid rocks (masses of the Shigar valley, of Skoyo-Turmik etc. and the sialic dykes connected with them) would therefore have been preceded by increasing regional metamorphism of the rocks of the volcanic-sedimentary formations which enclose them. This increase would naturally have been the consequence of the progressive rise of temperature due to their approach towards the actual outcrops, and, at the same time, of the persistence of weak stresses.

SUMMARY OF THE GENETIC PROCESSES.

The succession of events which have resulted in the formation of the rocks occurring on the right side of the Shigar valley can be summed up in the following way, taking for granted the existence of a magma of tonalitic type.

A tonalitic magma injected into the volcanic-sedimentary formation represented by the amphibolites, limestones, clays, marls and sandstones, crystallized as such in the northern part of the valley and caused the striking phenomenon of *feldspathization* in the surrounding amphibolites. In this way at the side of the tonalitic mass a belt of biotitic or amphibolic-biotitic plagioclase gneisses, of granitic aspect, was formed, which change outwards to biotitized amphibolites mottled by plagioclasic porphyroblasts, and finally to amphibolites.

In the southern part of the valley the tonalitic magmas, at their contact with calcareous-argillaceous rocks, became broadly contaminated by assimilation, resulting in a basification of the products of crystallization; in this way basic amphibolic rocks of dioritic or gabbric type were formed. Contemporaneously the surrounding rocks were transformed by contact metamorphism.

The rocks with granitic composition (granitic gneisses and gneissic granites) exposing at the southern central part of the valley, would be the product of the metasomatic reactions caused by the late introduction of silica and potash in the plagioclase gneisses of the marginal belt.

The big granitic dykes present at the lower part of the valley might be considered, however, as injected. Also in the Indus valley, precisely between the localities of Tungas and Gurbidas, where agmatitic rocks crop out, are clearly recognizable the effects of feldspathization and granitization of the amphibolitic host rocks.

THE LEFT SIDE OF THE SHIGAR VALLEY

In contrast to the right side of this valley, where plutonic granitic-dioritic rocks predominate, in that part of the left side mapped by me (from the source of the Shigar valley to the village of Shigar) rocks of granitic type occur only over very limited areas and are localized in the central part of the high ridge which connects the summit of Koser Gunge (6,403 m; 21,000 feet), to the Skoro-la. The remaining part of this slope is formed of paraschists, with the exception of a few extrusive basic rocks interbedded with pyroclastic materials.

The lithological types observed are very numerous as a result both of the variety of original sediments and of the different intensity with which they have been submitted to regional metamorphism.

This is the reason that the lithological correlations between the formations outcropping at different places in our valley are difficult. Fortunately, this difficulty is compensated by the relatively simple tectonic features of the region and by the presence of characteristic limestone horizons which are exposed for some kilometres without showing any substantial modifications of their aspects on account of the variations of the metamorphic conditions.

The formations which form the subject of this chapter have a NNW-SSE strike (and a ENE dip) in the northern part of the valley, which changes to NW-SE further south. Near Skoro Lungma the trend varies more rapidly and, at the mouth of the Bauma-harel Lungma, the strike is E-W, and the dip is northwards. For some distance therefore, the direction of the beds coincides with that of the Shigar valley (NW-SE). Because of this disposition of the terrains, it will be best to describe them successively, as they occur from the valley bottom to the highest zones.

PREVIOUS STUDIES

Before the Italian Expedition to Karakorum in 1954, knowledge about the formation on the left side of the Shigar valley was quite extensive but was limited to the lower parts of the outcrops.

Of the three geologists who have provided information about the nature of these terrains only DESIO has had occasion to cross all the series occurring here, whilst travelling from Askole, in the Braldu valley, via the Skoro Lungma. Unfortunately that excursion was made during such bad weather that detailed observation was virtually impossible.

G. DAINELLI (1) reports in detail the succession of terrains observed by LYDEKKER (1881), by himself (G. DAINELLI, 1933, pages 579-581) and by A. DESIO (1930 a, 1930 b) in the terminal part of the lateral valleys which enter near the villages of Hashupa (Daltumbore Lungma) and Skoro (Skoro Lungma) and compares the results.

It is not necessary to repeat the lithological successions observed by each of them, especially as the succesions do not agree and represent anyway only a small part of the series which occur on this slope. It will be sufficient to note that the predominant recurring types alternating in various ways are *limestones*, *dolomitic limestones*, *metamorphic limestones* (marbles and calciphyres rich in tremolite, etc.) *calc-schists*, *greenschists* (chlorite-epidote prasinites, actinolite schists, serpentine schists, serpentinites), *argillaceous schists* (black, brown, green, bluish and sometimes carbonaceous), and *granitic and plagio-clase gneisses and micaschists*. (P. ALOISI, 1933; P. COMUCCI, 1938).

G. DAINELLI also indicates the frequent presence of quartzites associated with the calcareous rocks.

Because of the medium trend of the rocks in this zone, the same author thinks that the outcrops of limestones and calcareous schists near Chutrun, in the lower Basha valley represent their direct continuation.

Opinions differ as regards the age of these terrains. R. LYDEKKER, having found some particles of Crinoids in a calcareous stratum calls this Rhaetic, and the levels below it Triassic; above this should be the Jura-Liassic or more recent terraines. Because of lithological similarities with a Silurian cal-careous-quartzitic belt observed by him a great distance from the Shigar

(1) G. DAINELLI published the results of the Italian Expedition De Filippi of 1913-14 only in 1933, that is after A. DESIO had published his notes (A. DESIO, 1930 a, 1930 b) about the observations made during the Italian Geographical Expedition to Karakorum in 1929.

valley (Nubra valley) G. DAINELLI tentatively classifies them as Silurian-Devonian and the rocks above and below this calcareous-quartzitic belt as pre-Silurian crystalline schists.

Information about the nature of the crystalline schists can be obtained only indirectly by studying the petrographic analyses made on samples of schists from zones south of the Shigar valley (P. ALOISI, 1933, page 235). These are represented by *granitic gneisses*, *biotite and amphibole plagioclase gneisses* (sometimes passing into amphibolites), *micaschists*, *amphibolites*, *prasinites and amphibolic rocks*.

Concerning the tectonics of this zone G. DAINELLI maintains that the calcareous-quartzitic belt (Silurian-Devonian) which occurs near the valley bottom on the left side of the Shigar valley, represents the core of a syncline with a NW-SE axis and a NE dip, enveloped in the (pre-Silurian) crystalline schists.

Since, according to this author, all the belts of calcareous crystalline rocks, with or without quartzites, could be of Silurian age, he thinks that, between the Braldu valley and the northern margin of the Deosai high-land, along the Mango Gusor-Marshakala line (i. e., perpendicular to the normal strike of the formations) there could be five-fold repetition of synclines with Silurian cores (G. DAINELLI, 1934, page 992). This is exactly the number of calcareous belts occurring here (or supposedly occurring) i. e., one in the Braldu valley, two on the left slope of the Shigar valley, one on the right and one on the left slope of the Indus valley below Skardu.

GEOLOGICAL CONDITIONS AND PETROGRAPHIC FEATURES

The trend of the formations occurring in the Shigar valley (outlined above) can be followed all along the valley side, thanks to the existence of the light calcareous beds which for some distance are interbedded with darker schistose terrains forming one of the characteristic lithological levels of this complex.

The calcareous beds run from the Braldu valley, entering the Shigar valley immediately west of the summit of Koser Gunge (21,000 feet; 6403 m). Here they dip, intersecting the side of the valley diagonally, and eventually reach the valley bottom near the village of Alchori; they then run for a few kilometres close to and parallel with the valley bottom between Hashupa and Skoro, before turning and rising towards the middle part of the Baumaharel Lungma where it becomes discontinuous.

The rocks underlying this calcareous belt therefore occur both north and south of the Hashupa-Skoro zone, from the bottom of the valley to gradually increasing heights in both directions. Southwards, because of the change in direction of the beds (east-west), they cover all the Bauma-harel Lungma whilst northwards they must penetrate deeply into the Braldu valley (but not into the Basha valley as G. DAINELLI supposed). On the whole the most characteristic and most widespread rocks are the labradorite gneisses.

The stratigraphically higher beds are thickest in the zone crossed by the Skoro Lungma and are represented mainly by slates.

In describing the Shigar valley formation I shall follow the order of succession of the beds from the bottom upwards grouping them into three zones (lower, middle and upper), each with characteristic lithological features.

THE LOWER ZONE (ZONE OF LABRADORITE GNEISSES).

The labradorite gneisses, which will be petrographically described below, not only form the most common rocks underlying the calcareous belt, but are generally interbedded with metamorphic calcareous beds in the lower part of this belt.

I found no labradorite gneisses in the outcrops north of Hashupa, but that does not mean that they are scarce or absent here, because my observations and sampling of material in the northern portion of the valley were, as I have already said, very scanty.

These gneisses, however, are very widespread between Skoro and Shigar and it is probable that they also occur, alone or interbedded with other rocks, in the surrounding zones, to the south and west, since analogous rocks have been collected by G. DAINELLI at the elbow of the Indus river above the Skardu basin and near Sermic (P. ALOISI, 1933, page 160, 167), and others have been observed by me on the right side of the Shigar valley, near Trachil (54 PZ-284), in the Indus valley, below Skardu, near the lake of Katzarah (54 PZ-1) and by A. DESIO near Tsordas (53-D 2).

All these rocks, despite a certain variability of composition, have a characteristic appearance: they show an alternation of very thin, irregular beds of quartzose lenses, and slightly larger bands of a grey-ashy colour, mottled by many well developed biotitic flakes, disposed irrespective of the bedding.

In the more common types (54 PZ-237, 239, 242) the bands of grey-ashy colour are formed by a fine, or very fine aggregate of *calcic plagioclase*, *quartz*, *muscovite* and *biotite.* The quantitative ratio of these four fundamental minerals differs from rock to rock and also in different parts of the same rock. The abundant *calcic plagioclase*, is always the most characteristic mineral; generally it corresponds to *labradorite* or *bytownitic labradorite* (1), but it can also be of a more sodic type, *andesine* (2).

Flakes of *muscovite*, varying in size and sometimes poikiloblastic, are always disposed parallel to the bedding thus determining the schistosity of the rock.

On the other hand, the *biotite* occurs transversely to the foliation surfaces; it nearly always occurs as well developed poikiloblasts enclosing grains of quartz, plagioclase and iron ore which appear as stripes parallel to the foliation surfaces. In some cases flakes of biotite, in which the cleavage planes (001) are perpendicular or transverse to the foliation, show greatest development parallel to this, i. e., perpendicular, or nearly so, to the cleavage planes (Plate 19, fig. 1).

Garnet is often present, and sometimes quite abundant; it has a light violet colour and is extremely poikiloblastic due to inclusions of lenticular grains of quartz aligned according to the foliation of the rock; quite often this garnet is in the form of lenses.

Common secondary minerals are *tourmaline* and *zircon.*

In some samples typical aluminiferous minerals such as *andalusite*, *kyanite*, *sillimanite* and *staurolite* are found.

These rocks, characterized by the presence of *calcic plagioclase* and large flakes of *biotite*, gradually give way, near the mouth of the Bauma-harel Lungma, to similar facies, rich in well-developed crystals of green hornblende (54 PZ-243, 245), (Plate 19, fig. 2). In the fine aggregate formed with the usual minerals, granules of *pistacite* and *clinozoisite* are sometimes also present.

In the labradoritic paragneisses interbedded with marbles (54 PZ-252) in the lower part of the calcareous belt, large crystals of *clinozoisite* which often include some calcite are abundant; also frequent are patches or bands very rich in *clinozoisite* and *calcite.*

Inside these paragneisses are found discordant amphibolic lenses, which, in some cases, could correspond to dykes. These are *amphibolites* in which the interstices left free of the very frequent crystals of *hornblende* are occupied

(1) $\alpha' > \varepsilon_q$; optic sign always positive; the composition of the plagioclases lies between 55% and 70% An.

(2) $\beta \approx \omega_q$; the maximum extinction angles of albite twins measured in the zone ⊥ (010) = = 24°-27° = 45-50% An.

by a granoblastic aggregate of *quartz*, and *labradorite*. *Garnet* is also present. Northwards from Alchori in the northern part of the Shigar valley, are the terrains below the labradorite gneisses. These come under the general term of *biotitic* and *biotite-amphibole schists*, with which small calcareous beds can be associated. A large calcareous bed, flanked by a smaller one, dips steeply from the slopes of the Koser Gunge immediately south of Sildi. Not far from the Sildi limestones some *amphibolites* (54 PZ-260) are also found, very similar to those occurring in the Turmik valley and in the surrounding zones. The amphibolites represent rocks which predominate between Sildi and Yuno (54 PZ-262, 262) where perhaps (my field notes are not very clear on this subject) biotitic augengneisses (54 PZ-261) also occur. These latter are formed mainly by *quartz*, *oligoclase* (enclosing not only numerous grains of quartz, but also biotite, muscovite, epidote, garnet and calcite) and *orthoclase* which encloses all the other minerals of the rock.

As a whole the rocks of the northern part of the Shigar valley show obvious similarities with the amphibolitic-calcareous formations of the upper branch of the Turmik valley, and with corresponding rocks observed in the Indus valley near Tungas, and can be considered equivalent to these.

In the *southern part of the valley*, where the formations strike east-west, the labradorite gneisses seem to pass into rocks of tuffaceous type, nearly always altered into greenschists. This is seen in the Bauma-harel Lungma, the lateral valley which leads into the village of Shigar.

At the mouth of the valley the labradorite gneisses become gradually darker, for the presence of increasing quantities of amphibole. Upstream rocks begin to appear, and later to predominate, which are greenish in colour, sometimes schistose, sometimes compact, and which are arenaceous or conglomeratic in appearance. No clear limit exists between the gneisses and green rocks, the two types being indented for a long distance, or irregularly alternated forming pockets, bands and lenses.

The green rocks correspond to *chlorite-epidote greenschists* (54 PZ-246) or *serpentine schists* and *actinolite schists*, but often in the groundmass formed by the association of these minerals typical of the greenschists there occur large crystals of *augite* (54 PZ-244) (Plate 19, fig. 3), or *hornblende* and *augite* (54 PZ-247) (Plate 19, fig. 4) sometimes idiomorphic and fresh, sometimes unweaved and partially weathered. They are clearly the products of transformation of the original volcanic materials, probably tuffs.

Sometimes, as it has been seen, they are so fine-grained as to assume the appearance of green slates (54 PZ-250), or coarse-grained and conglomeratic

(54 PZ-248). In the latter case the matrix which combines the elements of the volcanic rock can be formed not only of chlorite and epidote, but also of remarkable quantities of *calcite*. From the observations made I have the impression that in the lower section of the valley the finer argillaceous types predominate whilst, in the middle section, the coarser arenaceous and conglomeratic deposits are most prevalent.

Since, upstream, the terrains observed at increasing heights correspond to the stratigraphic succession of the Shigar valley, it is theoretically possible that these volcanic rocks represent a lateral facies of the calcareous belt and of the slates, as well as of the labradorite gneisses.

My observations in the Bauma-harel Lungma ceased half way between the mouths of the valleys leading to Thalle-la and Tusserpo-la (i. e., between Yaltsa Lungma and Tlathlung Lungma). From the alluvial materials collected at the highest point reached it can be deduced that in the upper basin of the Bauma-harel Lungma there must be some reddish *arenaceous paragneisses* (54 PZ-249), in whose fine-grained matrix are developed large albitic plagioclases with indeterminate limits, and *conglomerates* with large calcareous or marly elements cemented by an argillaceous reddish matrix.

Finally, on the right side of the Yaltsa Lungma, at a remarkable height, two light parallel streaks, probably corresponding to calcareous bands, are visible.

The Middle Zone (Zone of Calcareous Rocks).

This is the more easily recognizable zone, in the field and from a distance, and here the observations of geologists who have gone through this valley before me were concentrated. Very little, therefore, can be said about it beyond what I have written in the section on previous studies.

It will be sufficient to note that the calcareous or dolomitic-calcareous rocks, now transformed into layers of *marbles* (54 PZ-251) and *calciphyres* (among which those rich in tremolite (54 PZ-259) (Plate 20, fig. 1) seem particularly frequent), are interbedded with schistose rocks. These, in the lower part of this zone, often correspond to *labradorite gneisses*, sometimes mixed with calcareous material (54 PZ-252); higher up the common types are *greenschists* (prasinites, chlorite schists, schists rich in actinolite etc.) and black, grey, or green *slates*. The *quartzites*, shown to be both common and thick by G. Dainelli but not mentioned by R. Lydekker, have been met by me in infrequent thin intercalations. However, I have not given particular attention to this succession since it has already been the subject of detailed study by other authors. Perhaps for this reason I did not find the *granitic* and *plagioclase gneisses* mentioned by them.

Rocks of granitic type (54 PZ-238) were found only on the scree at the foot of this calcareous belt, but I could not locate their origin, because patches of morainic material, including granitic pebbles, partly covered this slope.

I want to call attention to the fact that the rocks interbedded with calcareous layers correspond to metamorphic grades which decrease rapidly upwards. Furthermore, apart from the greenschists and the granitic and plagioclase gneisses, they are represented, in the lower parts by widespread beds typical of the lower zone (labradorite gneisses), and in the higher parts by beds predominating in the upper zone (slates of different colour). Such distinctions are valid and possible only in the Hashupa-Skoro zone where the calcareous or calcareous quartzitic belt reach the valley bottom; northwards regional metamorphism affects, with considerable intensity, all the rocks, and thus the lithological differences between the different types of schists are hardly recognizable.

The Upper Zone (Zone of Slates).

The slates, which appear as intercalations even in the higher part of the middle zone, form the predominant rocks of the zone overlying the calcareous band; indeed it could be said that they occur continuously over extended areas and there is thus a gradual transition to rocks of arenaceous-phyllitic type.

I could easily see the succession of these types right along the Skoro-Lungma, from the village of Skoro to Skoro-la (5,074 m 16,644 feet;).

A little above the village of Skoro occur the *slates* which continue with no great variation of character, to the point where the valley narrows into a deep canyon; they have an almost constant strike, but the dip changes continuously due to very small accentuated folding which accounts for their large apparent thickness in the field. They are formed by the alternation of grey shiny slates, and darker almost black carbonaceous types, which are always very laminated and fragile, especially the darker ones.

They are formed with a very fine-grained *sericitic-quartzose aggregate* in which can be present variable quantities of *chlorite*; *sodic plagioclase* is scarce. Here and there depressed lenses formed with large quartz particles are present. More or less frequent, according to the type of rock, are dark graphitic streaks which are generally slightly discordant to the foliation surfaces of the rock (54 PZ-234, 235, 236) (Plate 20, fig. 2).

From the valley which enters on the left of Skoro Lungma, near the last inhabited locality, extends a large moraine formed exclusively by green rocks of the type observed in Bauma-harel Lungma. This means that these rocks, of volcanic origin, also occur in the basin of Skoro Lungma.

A little above the mouth of the canyon, which cuts deeply into the middle-upper section of the Skoro Lungma (Nang Brok), thin beds of *chlorite schists*, arenaceous phyllites (54 PZ-235) (Plate 21, fig. 1) and *quartzites* become interbedded with these slates. The *quartzites* of greyish colour, and especially the *arenaceous quartzites* (54 PZ-233), formed essentially of *quartz*, *sodic-plagioclase* and lesser quantities of *calcite*, *biotite* and *muscovite*, become more and more abundant ascending the canyon, and eventually are more abundant than the slates which seem here to have a greater crystallinity. The whole canyon is formed of subvertical beds of arenaceous quartzites which are thus more than one kilometre thick.

With the arenaceous rocks thin beds of micaceous schists, which resemble micaschists in appearance and undoubtedly correspond to the slates occurring below, are intercalated; less frequent are the intercalations of laminated biotitic gneisses and augengneisses, similar to those which occur higher up, near Skoro Katza (1).

Where the canyon widens again, *quartz-biotite gneisses* (54 PZ-232) appear near the top. These are rich in feldspar, and very foliated, with large flakes of biotite disposed on subparallel, discontinuous and irregular surfaces. These gneisses occur over a great distance, until under the Skoro-la they give way to outcrops of very variable appearance. These rocks are also seen to be heterogeneous under the microscope, and in them can be distinguished irregularly distributed areas with a different grain (Plate 21, fig. 3). The fine-grained parts are formed with an aggregate of *albite* with *quartz*, *muscovite* and *biotite*, inside which *porphyroblasts* of *albite-oligoclase* 10% An (2), ill-defined and full of inclusions, develop (Plate 21, fig. 4); other porphyroblasts of the same type seem independent of the fine-grained albitic aggregate. The quartz, alone, forms some portions of medium grain (Plate 21, figs. 3, 4).

About 400 m (1,400 ft) below the Skoro-la *amphibolites* (54 PZ-231) occur, very similar to those of the Indus-Turmik-Twar zone, but particularly rich

(1) Skoro Katza is an area of meadows under the Skoro-la, at a height of 3800 m (12,500 ft)

(2) $\gamma' < \omega_q$; positive optic sign; the maximum extinction angles of albite twins measured in the zone $\perp$ (010) = 10°-13° = 5-10% An.

in sphene. In places these rocks gradually lose their schistosity and assume a more distinctive grain. In this way large bands of amphibole-biotite gneisses (54 PZ-230) appear, having the appearance of dioritic gneisses, intersected by sialic veins and dykes. These gneisses are rich in sialic minerals, *andesine-oligoclase* (1) and *quartz*, united in rather fine aggregate inside which plagioclase porphyroblasts develop. These also are of andesinic composition, with no definite limits or forms.

Between these outcrops of basic rocks and the Skoro-la pass occur subvertical schistose rocks, crossed by aplitic and pegmatitic dykes. Sometimes the pegmatites isolate and enclose strips of the surrounding schists which assume the appearance of coarse-grained amphibolic patches.

I did not take any samples of these schists and I cannot, therefore, specify their exact mineralogical composition. They are very micaceous, and maybe amphibolic, and should correspond to schists which are found beyond the mountain-pass, on the slopes of the Braldu valley. Also these basic schists belong, in my opinion, to the Cretaceous amphibolitic formation.

In the more northerly part of the Shigar valley the stratigraphically equivalent rocks were affected by a more severe metamorphism has caused the transformation of the slates into *garnetiferous micaschists*, sometimes still remarkably *graphitic*. One of these (54 PZ-258), characterized by the intense, thin folding of the *muscovitic-quartzose* bands, exhibits large crystals of *garnet* and *biotite*, the latter with flakes disposed transversely to the surfaces of schistosity and enclosing very fine grains of graphite. In the muscovitic bands poikiloblasts of *albite* including micas, quartz, iron ore and graphite occur. It is worth mentioning the fact that the graphitic streaks contained in the micaceous bands maintain a constant direction across the crystals of albite.

Furthermore, the *arenaceous quartzites* (54 PZ-254) become more metamorphic in the outcrops north of the Skoro Lungma, but their appearance does not vary much.

In the northern part of the valley masses of granitic type also occur, which have invaded the formation of paraschists now indicated. As I have already said, I made only distant observations of the granitic outcrops and I can only say that they intersect the surrounding rocks in the middle part of the ridge which connects the Koser Gunge with the Skoro-la. The rocks collected in the alluvium of the Daltumbore Lungma (54 PZ-253) and of another valley to the north, enable me to say that these granites are rich in potash-feldspar.

(1) $\gamma' \mp \varepsilon_q$; negative optic sign; the maximum extinction angles of albite twins measured in the zone $\perp$ (010) $= 14^\circ$-$15^\circ = 30$-32% An.

Concerning the already mentioned differences in metamorphic facies observed in different parts of the valley it can be said that on the left side of the Shigar valley the variations of metamorphic grade occur rapidly both along and across the strike of the formations; the intensity of metamorphism increases from south to north and from east to west starting from the central part of the left side of the Skoro Lungma, where rocks of the lowest metamorphic grade occur, i. e., slates. Near Skoro Katza the metamorphism again begins to increase, also towards the east.

Once again a connection seems to exist between the intensity of regional metamorphism and the proximity of plutonic masses (mass of the right side of the Shigar valley; granitic and migmatitic masses of the Braldu valley). In this particular case the variations of metamorphism are more rapid than elsewhere.

ANALOGIES WITH OTHER HIMALAYAN FORMATIONS

The existence, on the left side of the Shigar valley, of rocks very weakly affected by regional metamorphism enables an attempt at some correlation with other Himalayan formations which occur in regions where metamorphic action of a certain intensity did not occur; such as, for example, those which extend south of the area mapped by me.

A first indication to guide my research is the frequent presence of amphibolites near the valley bottom and in the neighbourhood of the Skoro-la, of volcanic materials in the Bauma-harel Lungma, and of greenschists in the calcareous belt. All these basic rocks are surely the equivalents of the Cretaceous (Senonian) amphibolites and greenschists occurring in the Indus valley, in the Turmik valley and in the Basha valley, of which they in fact represent the direct east or south-east continuation. The rocks within which the basic schists are interbedded, that is all the complex represented by the terrains of the lower zone (zone of labradoritic gneisses) and of the middle zone (calcareous or quartzitic-calcareous belt), must therefore also be of Cretaceous age. This was also easy to understand on the basis of lithological similarities with the labradorite gneisses of the Indus valley and with the calcareous belts which are found in the Indus and Turmik valleys.

On the other hand the slates (of which I know no certain equivalent in all the zone from the Shigar valley to the Askore valley, where the rocks are much more metamorphic), are frequently interbedded in the upper part of the calcareous belt and are themselves, therefore, of Senonian or similar age.

The same considerations are also valid for the rocks of an arenaceous nature which occur above the slates, and which are interbedded with them.

As was to be expected, terrains similar to ours occur in the regions south of Skardu, in Ladakh, on, or near, those long bands of volcanic-sedimentary terrains of Cretaceous age which represent the metamorphic equivalents of the prevailingly amphibolitic formation which extends into our area between the Askore valley and the Shigar valley. Unfortunately, two distinct successions are present in these bands, both similar to the succession met in the Shigar valley; one Cretaceous, the other Eocenic. According to G. DAINELLI (1) who, following the observations of many other scientists, has made the most exhaustive analysis of these terrains, it is difficult in the absence of fossils to distinguish the Cretaceous levels from the Eocenic levels because of their lithological similarity. This consists "of the repeated alternation of argillaceous schists of different colour, of sandstones and of calcareous beds" and prove "at least the similarity of environmental conditions existing during the transition from one age to another" (G. DAINELLI, 1933; page 131).

No fossils have been found in the Shigar valley and therefore it is not possible to decide for sure if the slates and sandstones occurring along the Skoro Lungma can be compared with the Cretaceous levels or Eocenic levels of Ladakh. Because of this uncertainty, I should prefer to call them Eocene because of the extent of grey and dark slates which, according to G. DAINELLI (1933, page 131), represent the only element which enables "up to a certain point" the differentiation of Eocene levels from the Cretaceous levels.

The classification of the Shigar valley rocks as Eocene instead of Cretaceous is of little importance regarding the aims of the present work and, besides, I have mentioned the observations of DAINELLI about the similarity

(1) According to G. DAINELLI (1933, page 12-14; 130-131) the Cretaceous series is represented "chronologically, from the upper to lower members, by: 1°) zone of the conglomerates with elements of green eruptive rocks; 2°) locally, by the calcareous hippuritic beds; 3°) by a fairly thick zone of green eruptive rocks with which are associated brownish argillaceous schists" or: "1°) a fairly thick argillaceous arenaceous complex in which greenish sandstones prevail, with an interbedding of argillaceous schist and of thin calcareous beds; 2°) fairly coarse greenish sandstones, which in the lower parts often pass into a conglomerate or breccia in which granitic elements predominate". The Eocene series shows successions which vary a little in the many zones observed by G. DAINELLI (1933, page 72-73). Summing up it can be said that the conglomerates with elements of eruptive rocks of Danian age are succeeded, chronologically: 1°) by various coloured argillaceous schists interbedded with greenish sandstones (lower part of the lower Eocene); 2°) by grey or brownish argillaceous schists interbedded with sandstones and limestones (from Londinian to Auversian).

Since the Eocene along the Ladakh Indus valley forms the core of a syncline, the above-mentioned series are also found in inverted order, with the difference that the basal part of the lower Eocene is represented mainly by grey or brown sandstones instead of by various coloured schists.

of environmental conditions existing during the deposition of the materials which now form the two levels of different age. More important is to have found a good correlation between the terrains which, in the area mapped by me, succeed, with no break of continuity, the rocks of the amphibolitic formation and the terrains which along the Ladakh Indus succeed the rocks of the Senonian volcanic-sedimentary series. Such a correlation, in fact, enables one to affirm that the terrains occurring between the Askore valley and the Shigar valley (and also in the Braldu valley) represent the northward (or north-westward) continuation of the long outcrops of Cretaceous-Eocene rocks existing in Ladakh, in the Dras zone and in the Astor zone.

Apart from the certain lithological similarities between the regions of Ladakh and this part of Baltistan, it is possible that similarities also exist between the two regions in respect of general tectonic features; just as in the belt of rocks which runs parallel to the Ladakh Indus, so on the left side of the Shigar valley there could be present, as already supposed by G. DAINELLI (1943, page 992), an inclined syncline dipping north-east (in Ladakh the folds dip south-west).

In conclusion, the rocks occurring on the left side of the Shigar valley form a stratigraphically continuous succession ascending chronologically from the valley bottom towards the dividing ridge. The rocks of the lower zone, (represented by labradorite gneisses) and of the lower and middle parts of the calcareous or quartzitic-calcareous belt, are of Cretaceous age (Senonian) and not pre-Silurian and Silurian-Devonian respectively as thought by DAINELLI, or Triassic and Jurassic as thought by LYDEKKER (see page 142, 143); the slates and the arenaceous rocks are Senonian, or Eocene.

VI

GENERAL SUMMARY OF GENETIC PROCESSES

In this chapter I shall try to give, with the aid of the knowledge gained and the geological and petrological interpretations which I have gradually expounded in this work, a comprehensive picture of the general processes whose succession has brought about the constitution of the rocks which, at present, occur between the basin of Stak and the Braldu valley.

In the whole area mapped by me *two series* of rocks of very different age have been distinguished: the *one*, *pre-Cambrian* (*Salkhala series*), is limited to the Stak basin and is formed by an *originally argillaceous series* interbedded with moderate bands of calcareous rocks; the *other*, *Cretaceous* or *Cretaceous-Eocene* occupies the whole area east of the Stak valley, as far as the Braldu valley, and is formed by *basic schists of volcanic origin*, interspersed with rocks of calcareous, argillaceous and arenaceous type.

These two series make contact along the ridge which separates the Stak valley from the Askore valley and should show (on the basis of D. N. WADIA's observations in the southern part of the Astor, where the rocks have not been submitted to metamorphism), a definite angular discordance. However, this is not visible here because of the successive phenomena of tectonic deformation which has involved both series giving them a concordant schistosity.

Compared with the observations made in the Nanga Parbat area it might be inferred that also in the Stak zone the argillaceous pre-Cambrian rocks must still have been slates when, in the Senonian, *volcanic activity*, synchronous with the later geosynclinal phase, began, on the bottom of the Tethys.

During the volcanic activity large quantities of *pyroclastic products* were ejected and less frequently *lava-flows*. At the same time deposition of *calcareous, argillaceous and arenaceous materials* continued and these became interbedded with the pyroclastites.

The volcanic activity was of essentially basic nature, *basaltic* and, sometimes, *andesitic* and at some point, judging from the slightly sodic character of these rocks in some zones, there also occured the emission of *basalts of* *spilitic type.* This also seems to be indicated by the frequent siliceous deposits (chert), the high Mn content of some rocks and the presence, among the lavas, of keratophyres (spilite-keratophyre association).

While the volcanic activity became weaker and died out, the deposition, at the end of the Cretaceous and, maybe, in the lower Eocene, of clay, sandstones, conglomerates and limestones continued. These sediments, which in our area occur on the left side of the Shigar valley, represent the most recent types existing, or observed, in this part of Karakorum.

The first tectonic movements involved both the pre-Cambrian and Cretaceous rocks and resulted in the dislocation and, in the regions mapped by me, the weak metamorphic transformations causing the appearance of rocks of the epizone (greenschists, slates, etc.).

Almost simultaneously there occurred the *intrusion of basic magmas*: gabbros, norites, gabbrodiorites, hypersthene diorites and ultramafic rocks. Thus, inside the now schistose rocks of the volcanic-sedimentary series, were formed either conspicuous masses, such as the dioritic-noritic Twar mass, or widely distributed smaller masses of hypersthene diorites, norites and ultrabasic rocks (now transformed into basic amphibolites).

Also, in some places the pre-Cambrian slates were injected by these basic magmas. To this intrusive phase, therefore, are attributed the small discordant mafic masses occurring in the Stak valley, not far from the confluence with the Indus river, and may be also parts of the long bands or concordant lenses of amphibolites seen in the upper Stak valley, near Kulankae.

The massive basic rocks correspond to the extrusive rocks inside which they are placed and must be considered as the normal late accompaniment of the basic extrusions (gabbro-peridotite association).

The original composition of these magmas has without doubt been changed, locally, by *the assimilation* of extraneous rocks.

An example of chemical modification caused by magmatic assimilation would be shown by the amphibole-gabbros found at about the contact between the quartz diorites of Twar and the limestones of Mulakor.

Mafic masses of this type (Twar) may also show clear examples of regular variations of composition in a vertical direction (the more sialic rocks can be found at the upper part of the pluton). Such variations, supposed to be the consequence of the process of magmatic differentiation by gravity, would be emphasized by the autometasomatic replacement promoted by the sialic-alkaline residual melt formed during the fractional crystallization.

After the formation of the mafic masses orogenetic stresses began again (or continued) while the last great petrogenetic event which has affected this region was being prepared i. e., the appearance of the *sialic rocks*. Some of these, were formed by injection in a mobile magmatic state, as indicated by the granular texture of the rocks and the neat boundaries with the country rocks, in which typical contact minerals were developed as a result of thermal action induced in them. Other sialic rocks were formed by a more complex series of events, attributable on the whole to metasomatic processes.

To the first type, that is to the *intrusive rocks of magmatic origin*, belong some parts of the granitic-dioritic mass of the Shigar valley. These rocks must also have undergone modifications of their original composition by *processes of syntexis* such as occurred in the southern part of the Shigar valley where the intrusive rocks were basified by the assimilation of calcareous and argillaceous-calcareous rocks.

A similar formation (according to the descriptions of G. DAINELLI and D. N. WADIA) is the large granitic-dioritic mass of the central Baltistan (*transhimalayan granite* of G. DAINELLI and *hornblende granite* of D. N. WADIA) of which the Shigar valley mass represents an isolated portion probably connected at some depth. I mention this pluton, although it occurs outside the area considered by me, because the genesis of the magmatic and metasomatic rocks of granitic type occurring in our territory is probably connected with it.

Near the magmatic masses and sometimes also far from their visible outcrops, the pre-Cambrian slates and the rocks of the volcanic-sedimentary series were affected by granitizing materials. As a result of mineralogical and chemical transformations caused by the introduction of sialic alkaline materials into them, *migmatites* were formed. These, represented by "plagioclase gneisses" and "granitic gneisses", vary in appearance, texture and chemical and mineralogical composition according to the original composition of the granitized rocks (amphibolites, slates, etc.), the nature of the granitizing material (sodic, potassic, sodic-potassic) and the intensity with which this has acted on them.

At the contact between tonalite and amphibolite of the right slope of the Shigar valley and within the amphibolite of the Skoyo-Turmik zone the most evident manifestation of the Na-metasomatism can be seen. The metasomatic products are represented by *plagioclase gneisses* completely devoid of K-feldspar and characterized by a remarkable development of the oligoclase porphyroblasts. Such sialic gneisses, which more or less gradually pass to the basic schists, still preserve some characteristics of the amphibolites which would be derived by feldspathization.

At the roof of the tonalite mass of Shigar, the plagioclase gneisses form a long belt and thus represent a "metasomatic aureole" of the same mass; the Skoyo-Turmik gneisses show the same textural characters exhibited by the gneisses of the Shigar valley; they constitute a relatively extensive mass and are separated from the host rocks by an agmatitic belt. These two large outcrops of plagioclase gneisses are connected to each other by many sialic veins and intercalations of aplitic aspect having also the same chemical and textural characters as those of the plagioclase gneisses.

There is therefore every reason to think that the sialic gneissic mass of Skoyo-Turmik would be genetically connected with the plagioclase gneisses of the Shigar valley and that, as the latter, it might also be interpreted as a "metasomatic aureole" of an underlying pluton and, precisely, of the big "granite-diorite" mass which occupies almost the whole area of central Baltistan; the tonalites of the Shigar valley represent a portion of the above-mentioned pluton.

Either the Cretaceous metamorphic formation (i. e., at the Shigar valley) or the pelitic pre-Cambrian schists of the Stak valley were affected by *Na-K metasomatism.*

The *granitic gneisses* of the Shigar valley which pass gradually to a more massive facies (i. e., gneissic granites) constitute the southern part of the long belt of feldspathized rocks which envelop the tonalite-gabbrodiorite mass. The relations between the granitic gneisses and the plagioclase gneisses, the obviously late origin of the K-feldspar and the alterations and replacements by it caused on the pre-existing minerals, seem to indicate that the granitic gneisses are the final result of a metasomatic process, begun with sodic character (genesis of plagioclase gneisses) and continued with more and more potassic character.

Thus the plagioclase gneisses and the granitic gneisses would represent the product of two successive stages of a unique process of metasomatism: the first was of sodic character while the second was prevailingly potassic.

The superimposition of the K-metasomatism on the rocks previously altered by the Na-metasomatism might be a favourable argument to the hypothesis that *the granitizing fluids, sodic as well as potassic, have derived from the same source and that they travelled along the same paths.*

Only in rare cases the correspondence in space of these two metasomatic actions is not shown; for example, some portions of the metasomatic aureole of the Shigar valley's pluton do not show any effect of the Na-metasomatism, but, on the contrary, have been changed into K-felspar metacrystal-rich gneisses by the K-metasomatism. It seems to confirm, therefore, that the two stages of the metasomatic process have taken place at two distinct times.

Intense Na-K metasomatic transformations had affected the pre-Cambrian shale of the Stak valley and therefore migmatites which are in various degrees rich in paleosome are formed (i. e., migmatitic augengneisses, banded gneisses, granitic gneisses). In this zone distinct stages of metasomatism have not been individualized as had happened in the Shigar valley, but the Na and the K seem to have been supplied contemporaneously, even when the first formed metacrystals were the K-feldspars.

The granitization in the Stak zone would occur under a metamorphic condition remarkably higher than that under which the feldspathization or granitization of the Cretaceous amphibolite formation had occurred; the proof of these facts is provided by the relatively calcic plagioclase metacrystals and by the presence of bands of pegmatitic gneisses in the more evolute migmatites.

The Cretaceous amphibolites which are in contact with the pre-Cambrian rocks (right slope of the Askore valley) were also involved during the same process of granitization. So it is possible to establish that *all the sialic manifestations observed in the territory between the Stak and the Shigar valleys whether they are of magmatic or metasomatic origin, are of post-Cretaceous age.*

Concerning the distribution of the isogradic metamorphic rocks in the territory under consideration, it has been repeatedly noticed that the relatively higher grade metamorphic rocks are always found near the sialic rocks of metasomatic origin and that, away from the intensively feldspathized zone (metasomatic aureole), the regional metamorphism decreases gradually. In other words, around the "metasomatic aureole" of the pluton there are belts of rocks of decreasing grade of metamorphism. The author indicates these belts as "circum-plutonic regional metamorphic aureole" in analogous with the term "contact metamorphic aureole". The difference between them, however, is that the first is much larger and irregular than the second.

At the Skoyo-Turmik zone, on both slopes of the Shigar valley and also in the lesser known Braldu valley, the same distribution of the metasomatic and metamorphic rocks is clearly shown. It permits us to establish that *metamorphism and metasomatism are closely related between them*, and that the uprising of the sialic plutons is accompanied generally by a progression of the regional metamorphism.

Furthermore, it can be observed that usually the rocks affected by the Na-metasomatism (i. e., plagioclase gneisses) occur together with the medium grade metamorphic rocks of upper mesozone, while those affected by Na-K metasomatism (i. e., granitic gneisses) are accompanied by higher grade metamorphic rocks of meso-katazone. Thus, *the grade of metamorphism of the rocks which envelop the metasomatic formations depends on the nature and intensity of the metasomatism.*

VII

DESCRIPTION OF THE ROCK SPECIMENS

THE ROCKS OF THE BASIN OF STAK

LOW AND MIDDLE STAK VALLEY

54 PZ-27→33, 59→61

54 **PZ-27.** – Quartz-feldspathic gneiss with biotite, epidote and garnet; *left side of the valley, at the mouth.*

This very light rock, with the appearance of an aplitic gneiss, forms the main type near the confluence of the Stak river with the Indus river. It is often interspersed with darker rocks, much richer in biotite or amphibole so that, on the whole, the formation has a banded appearance.

The rock contains many shear surfaces along which coloured minerals, enclosed in the fine-grained quartzose or quartzose-feldspathic aggregate which is clearly blastomylonitic, are very often disposed.

Also outside of the obvious shear surfaces the *quartz* occurs as small grains suturated in a manner typical of the tectonites. Much better developed than the quartz, are the crystalloblasts of plagioclase (30% An) which often enclose numerous rounded grains of quartz. Para-and postcrystalline deformations (displaced fractures and bending of the twinning lamellae) are recognisable in these crystals.

The *biotite*, of brown-greenish colour, has its thin flakes unweaved when it is contained in the shear surfaces, but in other cases has normal flakes.

Epidote, sometimes a little ceriferous, and *garnet* are abundant. In some places *green hornblende* is present in small quantities.

54 **PZ-27a.** – Quartzose-feldspathic gneiss with hornblende, epidote and biotite; *left side of the valley, at the mouth.*

This rock corresponds to those slightly darker bands which alternate concordantly with the gneisses of aplitic appearance, as 54 PZ-27.

In textural features the rock is not very different from 54 PZ-27, but it is more intensely laminated so that its blastomilonitic character appears more evident. The quartz is in suturated granules also in this rock while the *plagioclase* (28-31% An) appears with large porphyroblastic particles, often much better developed than those observed in the rock described previously.

The orientated femic minerals are located on the shear surface and between them *green hornblende*, and also *epidote*, are very abundant; however biotite is very rare.

The postcrystalline deformations in the feldspathic porphyroblasts are very scarce; the growth of the larger crystals must have occurred after the principal phase of movement.

54 **PZ-28.** – Biotite-kyanite-garnet paragneisses; *2 km below the village of Kurchung*. (Analysed rock).

This schistose rock is formed of alternating light and dark beds, of irregular thickness; on the surfaces of schistosity garnet crystals protrude in the form of small nodules, while in the sections perpendicular to the surfaces of schistosity the sialic minerals appear in the form of lenses or « augen ».

Under the microscope the dark beds appear to be constituted of reddish biotite, muscovite, kyanite and garnet. The *biotite* and *kyanite* are often associated and occasionally small portions of the mica are disposed along the planes of foliation of the kyanite. In these dark bands, the *muscovite* is not found in large quantities, but where sialic elements are also present it is more abundant. The *garnet* forms well-defined porphyroblasts.

The light beds are constituted of *quartz* and *feldspar*; associated with which numerous crystals of *kyanite*, disposed according to the schistosity of the rock, and also particles of *garnet* are found; *biotite* and *muscovite* are either absent or very scarce. These beds are interrupted by lenses or nodules. For the most part the beds are formed of quartz injected by slender veins of potash-feldspar. As for the nodules and lenses they consist either of *potash-feldspar* or of associations of this mineral with quartz and with some plagioclase 20-25% An; the potash-feldspar is represented both by *orthose* and *microcline* with irregular or graded twinning. Very few nodules are formed of *zoisite* β.

The kyanite crystals are best developed in the light beds and here they are distinctly more poikiloblastic. In these beds, moreover, the kyanite is often disposed in swarms and forms areas in which it is occasionally associated with zoisite.

The garnet is often poikiloblastic, including quartz and biotite.

Among the accessory minerals *rutile* is very common while zircon and iron ore are much rarer.

54 **PZ-29.** – Quartzose-feldspathic gneiss with biotite, muscovite, garnet and kyanite; 3 *km above the village of Kurchung*. (Analysed rock).

In this zone the rocks are formed of an alternation of light beds of aplitic appearance, containing garnets and thin short stripes or small lenses of dark material, and of dark-reddish beds similar to those observed in the Kurchung valley (54 PZ-28). The sample is from one of the light beds.

The essential components are: potash-feldspar, quartz and, in smaller quantities, sodic plagioclase.

Well-developed and very elongated particles of *quartz* form thin and discontinuous bands, and stretched and depressed lenses immersed in an aggregate of feldspar and medium-sized quartz grains. From this matrix large feldspar porphyroblasts, for the most part *orthoclase* or *microperthite*, protrude.

In these sialic bands remarkably large crystals of *garnet* and isolated particles of *kyanite* in parallel stripes are found. Biotite is totally absent.

In the transition towards the darker bands one finds first thin beds or elongated lenses of *muscovite*, with a little *biotite*; further on the dark mica becomes more abundant. Garnet is also frequent, while kyanite is not present. *Rutile* is common.

This rock has been analysed (table 2, page 13); its composition corresponds to that of the *engadinitic granites* belonging to the leucogranitic magmas of NIGGLI.

54 **PZ-30.** – Quartzose-feldspathic gneiss with biotite-garnet-kyanite; *left side of the valley, above the village of Kurchung.*

The rock represents a particular facies, rather abundant here, of the gneissic formation represented by the alternation of dark micaceous-kyanitic-garnetiferous beds and quartzose-feldspathic beds. On a prevailingly quartzose-feldspathic matrix very thin streaks of the minerals characteristic of the dark bands are disposed always parallel to the general schistosity of the formation.

Under the microscope it can be seen that the *quartz* and *feldspars* are not uniformly distributed, but well-developed particles of the former, form very thin elongated bands alternating concordantly with feldspathic or quartz-feldspathic bands which sometimes combine into bands of greater thickness or patches of considerable extent.

Potash-feldspar predominates between the feldspars, both in the form of *microcline* (and probably of orthose) and *microclinperthite* (and perthite). *Sanidine*, easily distinguished by traces of well definite cleavage and by the optic angle = 0°, or nearly 0°, is also present. *Albitic-oligoclasic plagioclase* is much more scarce. At the contact between the potash-feldspar and plagioclase myrmekite is sometimes formed.

These feldspars are generally of average size, but in some cases they show a porphyroblastic development.

The *quartz*, in these feldspathic bands, is nearly always represented by fine-grained particles localized in patches or in short streaks and separated from one another by potash-feldspar which is insinuated between them. In some cases the quartz grains are enclosed in larger particles of feldspar.

Biotite, *muscovite*, *kyanite* and *garnet*, in isolated crystals disposed according to the surfaces of schistosity of the rock, form parallel streaks inside the feldspathic bands.

54 **PZ-31.** – Biotite-muscovite-kyanite-garnet paragneiss; *on the right side of the valley, near the ridge, at a height of about 4,500 m (15.000 ft).*

This rock is very similar to 54 PZ-28 but on the whole has a more reddish colour, due probably to an initial process of alteration.

This sample represents the most widespread type on the ridge, at least at heights above 4,000 metres (13.000 ft).

54 **PZ-32.** – Quartzose-feldspathic biotite-kyanite-garnet gneiss; *on the right side, 3 km above the mouth in the Indus river, at a height of about 3,600 m (12.000 ft).*

This rock is formed of a thin alternation of dark reddish beds, with *biotite*, *muscovite*, *kyanite*, *garnet* and *quartz* and of light quartzose feldspathic beds, in which the micas are rare or missing while the *kyanite* and also *garnet* are present.

The characteristics of this rock are similar to those described for samples 54 PZ-28 (page 164), 54 PZ-29 (page 165), 54 PZ-30 (page 165).

54 **PZ-33.** – Pyroxene-amphibole-garnet hornefels; *on the right side, at the same height as Kurchung; about 200 m (650 ft) above the bottom of the valley.*

This rock occurs between the banded gneisses 54 PZ-32 type, but, because of abundant scree it was not possible to decide on the spot whether it is a dyke or an interbedded type of original sedimentary nature.

The light coloured fine-grained rock has a slightly schistose texture.

Under the microscope it can be see that the sialic elements, quartz and plagioclase, are combined in fine patches or lenses elongated in a certain direction and are separated by an aggregate of mafic minerals disposed in parallel streaks in which the individual particles have not orientated disposition.

Pyroxene, garnet and amphibole are very abundant, especially the first two, although biotite is scarce.

The pleochroic *pyroxene*, of a greenish colour and with an angle of extinction $c : \gamma$ of about 40°, corresponds to a *diopsidic-hedembergitic* term.

The amphibole is a pleochroic *hornblende* ranging in colour from a light green to a reddish-brown, and with an angle of extinction $c : \gamma = 18°\text{-}20°$.

Pyroxene and amphibole, with a little *biotite*, always form small particles which have combined or grown together in very different ways.

The *garnet*, always in small or medium sized crystals, has a light rose colouration.

Green hornblende passing into actinolite, and chlorite are found as products of alteration.

The aggregate of the mafic minerals is dotted by grains of iron ore.

Rutile is present in small quantities as a secondary mineral.

54 **PZ-59.** – Hornblendite; *left side of the valley, 2 km from the mouth.*

This rock was taken a brief distance from the 54 PZ-60 sample and it is a common facies of the femic mass occurring in this part of the valley.

The sample is formed almost exclusively of large crystals of green *hornblende* in which are enclosed grains and very thin needles of iron ore formed by the segregation of the amphibole.

Also *biotite* is present, which sometimes fades away into the amphibole, so revealing some of the processes of the alteration of one mineral into another. Grains of *epidote* and *rutile* are rare.

54 **PZ-60.** – Quartzose-feldspathic gneiss with biotite, epidote and garnet; *on the left side of the valley, 2 km from the mouth.*

The sample is representative of a mass of aplitic appearance which is developed near amphibolitic rocks (54 PZ-59) into which it passes through the interspersed amphibolitic gneisses with light much laminated and folded quartzose-feldspathic bands of aplitic or pegmatitic appearance.

The mineralogical composition of this rock is entirely similar to that of the gneisses 54 PZ-27 type (page 163). In structure however it approaches either to the 54 PZ-27 type or the 54 PZ-27a type (page 163), since some portions have medium sized crystals of plagioclase (28-30% An) while other portions have better developed feldspathic particles.

54 PZ-61. – Amphibolite; *left side of the valley, at the mouth.*

This rock is found inside dark and reddish garnetiferous gneissic micaschists, which are little different from 54 PZ-28. It is probably a dyke.

The rock is formed essentially of hornblende and plagioclase. The schistose texture is given by the orientation of the amphibole.

The *hornblende*, of greyish colour, is very slightly pleochroic and has an angle of extinction $c : \gamma = 17^{\circ}\text{-}18^{\circ}$. The *plagioclase* is labradorite with 50-60% An.

These minerals are accompanied by *clinozoisite.*

54 PZ-42. – Biotite-muscovite-kyanite-garnet paragneiss; *south-east of Kulankae, at a height of about 3,600 m (12.000 ft).*

This dark coloured rock has a uniform composition very different from that of the dark bands of the facies common in the Stak basin.

54 PZ-43, 43a. – Biotite-epidote-garnet gneiss rich in calcite, and associated amphibolites; *south-east of Kulankae, at a height of about 3,600 m (12.000 ft).*

Amongst the more common pelitic facies of the zone of Kulankae, similar to the types described up till now, there are concordantly interbedded rocks characterized by a fairly high calcite content recognizable in the field only by the presence of amphibolic lenses or nodules a few centimetres to a few decimetres across. These rocks are also formed of an alternation of fine lighter and darker beds, or, more often, are soaked by sialic material which forms irregularly distributed patches.

The most widespread type of these rocks (54 PZ-43a) corresponds to a *biotite-epidote-garnet gneiss rich in calcite.* The *biotite*, which is very abundant, is not always orientated according to the surfaces of schistosity. *Epidote*, in well developed particles, is abundant, *garnet* is rather scarce, while *sphene* is relatively frequent. Here and there, always localised in the larger micaceous bands, a certain quantity of *calcite* is found.

Green *hornblende* however, is very scarce and occurs in *quartzose-feldspathic* patches.

The separation of the micaceous-epidotic bands and the sialic portion is not precise. *Quartz* and feldspars, represented almost exlusively by *plagioclases* 30 - 40% An, are uniformly distributed in the rock.

The *amphibolic lenses and nodules* (54 PZ-43) enclosed in these calciferous rocks correspond to amphibolites formed almost exclusively of large crystals of green hornblende (often poikiloblastic due to inclusions of quartz), of *quartz*, and of *plagioclase* varying in composition from grain to grain (from 22% to 45% An) and often enclosing quartz grains. Few elements of epidote, biotite and sphene accompany these minerals.

All these rocks are intersected by small quartzose or plagioclasic dykes (oligoclase-andesine) which are sometimes concordant, sometimes discordant. Thinner veins are filled up by *quartz*, *calcite* and *chlorite*.

54 PZ-44. – Garnet-biotite-kyanite banded gneiss; *on the slopes southeast of Kulankae, at a height of about 3,900 m (13.000 ft).*

This sample is formed by the alternation of thin light and dark beds, irregular in thickness and tiend, and slightly « augengneissic » due to the presence of porphyroblasts of garnet and feldspar. The abundance of garnet gives the rock a bumpy texture and generally a pink violet colour. This is one of the most widespread facies of this zone, and is much closer to the types observed in the lower Stak Valley (54 PZ-28, 29, 30).

Under the microscope it can be seen that from an aggregate of medium and medium to fine grained minerals porphyroblasts of *garnet* and *potash-feldspar* protrude; the latter is particularly widespread in the light beds where the larger crystals form some swellings. Other thinner light beds are formed solely of *quartz*, or of quartz and a little *plagioclase*.

Besides the garnet *kyanite* is also abundant, *biotite* is scarce whilst muscovite is absent. Rutile is very frequent between these subordinate minerals.

A later concordant vein, formed wholly of *plagioclase* is distinguishable between the various parallel beds.

54 PZ-45. – Biotite-garnet banded gneiss; *near Kulankae, on the left side, a little above the valley bottom.*

This rock, similar to the banded gneisses already described, is particularly rich in *biotite*.

54 PZ-45a. – Pegmatitic gneiss; *near Kulankae, a little above the valley bottom.*

Between the banded gneisses 54 PZ-45 type there are concordant dykes of pegmatitic gneisses with large elements of *muscovite*, whose boundaries with the surrounding rock are not generally well defined. At the contact of one of these a particular facies has been observed which corresponds to a *hornfels* with *garnet* and *pyroxene* in which an irregularly twinned feldspar seems to replace the garnet.

54 **PZ-46.** – Aplitic garnetiferous gneiss; *near Kulankae, a little above the valley bottom.*

This light rock, with thin stripes of micaceous material, passes laterally into the banded gneisses (54 PZ-46a) which form the more common facies of the migmatitic formation of Stak.

The rock is formed essentially of *quartz*, *orthoclase*, and of much smaller quantities of *plagioclase*. *Biotite*, often altered into chlorite, *muscovite* and *garnet* are scarce.

The feldspars are well developed and bright in the larger bands, whilst in the enclosing bands muscovite and biotite are turbid for the presence of sericitic products.

54 **PZ-46a.** – Biotite-garnet paragneiss; *near Kulankae, a little above the valley bottom.*

This rock is very rich in micas, and this, together with the relative scarcity of feldspar, makes it almost a micaschist. These rocks are often crossed by later pegmatitic dykes.

54 **PZ-47.** – Garnetiferous amphibolite; *near Kulankae, a little above the valley bottom.*

This rock represents a band only 20 cm thick developed in the proximity of a pegmatitic vein (54 PZ-46a).

The rock rather fine-grained and formed of a well cemented aggregate of *hornblende* with variable pleochroism from a light yellow-rose colour to light brown. In the interstices of the amphibolic aggregate one finds *garnet* and *quartz* and between them isolated fragments of *plagioclase*. *Epidote* is very scarce.

54 **PZ-47a.** – Aplitic garnetiferous gneiss; *near Kulankae, a little above the valley bottom.*

Rocks of this type are interspersed, as beds of sometimes considerable thickness, between the dark biotite-garnet gneisses. They are formed exlusively of *quartz*, sometimes in thin beds, *orthoclase* and *microline*, and a few well-developed particles of *oligoclase*. The *feldspars* sometimes enclose quartz. The few flakes of *muscovite* are placed parallel to each other. Biotite is very rare but *garnet* is more frequent.

54 **PZ-48.** – Muscovite gneiss with biotite and garnet; *near Kulankae, a little above the valley bottom.*

This rock forms a belt a few metres thick inside the muscovite-biotite paragneisses (54 PZ-48a) and represents a rather particular facies of the Stak formation. Light grey in colour, it has very thin rectilinear lighter and darker bands, though the latter are never really dark, but mostly greyish due to the presence of very fine biotitic elements distributed on a light matrix. Only here and there do relatively large bands (from a few mm to 1-2 cm) appear and these are obviously similar to the paragneiss between which the rock under examination is developed.

Under the microscope it can be observed that from a matrix formed of about equal quantities of uniformly distributed *quartz*, *potash-feldspar* and *plagioclase*, protrude many micaceous flakes (*muscovite* and *biotite*) and some *garnet*.

54 **PZ-48a.** – Muscovite-biotite-garnet paragneiss; *near Kulankae, a little above the valley bottom.*

This sample is enclosed between light gneiss (54 PZ-48) and amphibolites 54 PZ-49.

On a matrix formed of *quartz* and smaller quantities of fine grained particles of *albite-oligoclase* (potash-feldspar is a secondary mineral) are distributed *muscovite*, *biotite* and *garnet*.

54 **PZ-49.** – Epidote amphibolite; *near Kulankae, a little above the valley bottom.*

These amphibolites, enclosed between paragneiss of pelitic origin form a belt about 50 metres thick and are sometimes schistose or of somewhat massive texture.

Microscopic examination of a sample with scarcely visible schistosity has shown that the main mineral is *green hornblende* in well-developed particles with which are associated remarkable quantities of a fairly ferriferous type of the *epidote* group.

Quartz and *plagioclase*, sometimes as small isolated particles, sometimes combined into small patches are present in lesser quantities. The plagioclases, nearly always well twinned, correspond to *oligoclase* 30-35% An.

Sphene is relatively abundant among the secondary minerals.

54 **PZ-50.** – Garnetiferous amphibolite; *near Kulankae, a little above the valley bottom.*

Fine-grained rocks similar to these form a thin and irregular belt which in places separated the amphibolites 54 PZ-49 type from the micaceous-garnetiferous paragneisses 54 PZ-50.

This rock is similar to 54 PZ-47 except that it has a finer grain and the *garnet* is much more abundant.

54 **PZ-50a.** – Muscovite-biotite-garnet paragneiss; *near Kulankae, a little above the valley bottom.*

This rock, which formes belts a few metres thick alternating with garnetiferous amphibolites, is very similar to the paragneiss 54 PZ-48a.

54 **PZ-51.** – Clinozoisite-pyroxene-biotite hornfels; *near Kulankae, a little above the valley bottom.*

This rock forms a belt of about 40 cm inside the amphibolites which are interspersed as beds or lenses with the paragneisses, and appear to be injected with thin quartzose, or quartzose-feldspathic veins, in association with which calcic silicate should have formed. The rest is represented by crystalline limestones which here and there enclose amphibolic nodules.

The main mineral is *clinozoisite* in poikiloblastic crystals, associated with a *pyroxene* of *diopsidic* type ($c : \gamma = 36^0$-37^0) and flakes of *biotite.* A little *sphene* and ferriferous *epidote* accompany these minerals and here and there calcite also occurs sometimes as later veins.

In some interstices one finds *plagioclases*, irregular in form and twinning which are associated with *quartz*, *clinozoisite* and *diopside* in such a way that they appear to be of contemporaneous formation.

54 **PZ-52.** – Leucogranitic gneiss with muscovite and garnet; *left side of the Kutiah valley, in the scree of a valley which descends directly from an isolated peak about 5,500 m (18.000 ft) high.* (Analysed rock).

This rock evidently comes from the upper part of a summit which is easily distinguished by the light (almost white) colour of its walls. This is a facies occurring only in the Kutiah and Goropha valleys.

The sample is formed almost exclusively of *quartz*, *potash feldspar* and *plagioclase* 26-27% An in just about equal quantities. As in the other rocks, the plagioclase crystals have a homogeneous composition.

Here the large quartz particles also form beds or elongated lenses, but the feldspars which sometimes enclose them are of smaller dimensions.

Muscovite, arranged in parallel sometimes discontinuous belts, is present as beautiful idiomorphic flakes; *biotite* is very scarce. Rare, well-developed crystals of *garnet* are present.

Epidote and apatite are found in smaller quantities.

54 **PZ-53.** – Aplitic gneiss with muscovite and garnet; *on the ridge on the left side of the upper valley.*

This rock has the appearance of an aplitic garnetiferous gneiss. *Quartz, potash-feldspar, albite-oligoclase or oligoclase* are present in about equal quantities and are uniformly distributed in the rock. The quartz also forms some elongated lenses parallel to the general schistosity of the rock. The feldspars somentimes enclose grains of quartz.

Muscovite forms thin beds, or is present as isolated flakes while biotite is very rare. *Garnet* is frequent in large poikiloblastic crystals. Tourmaline, zircon and rutile are accessories minerals.

54 **PZ-53a.** – Biotite-garnet banded gneiss; *on the ridge on the left side of the upper valley.*

This rock shows a thin alternation of light and dark beds and is sometimes interspersed with facies of aplitic appearance 54 PZ-53 type.

Under the microscope very rich bands of *biotite* and *garnet* separated by light bands almost devoid of coloured elements can be picked out while broader zones show a more uniform distribution of the different mineralogical constituents.

Muscovite, tourmaline and rutile are rare.

On the whole the rock is very similar to the banded gneisses already described, but is devoid of kyanite.

54 **PZ-54.** – Biotite-muscovite garnet gneiss with feldspathic porphyroblasts; *on the ridge on the left side of the upper valley.*

This rock forms a very rare facies in this formation. Macroscopically it shows a schistose texture due to the orientated disposition of the feldspathic porphyroblasts or of the feldspathic lenses. Small daık biotitic pockets are typical.

Under the microscope it is seen that biotite and muscovite do not have any defined orientation. From a medium-fine grained matrix, formed of *quartz, biotite, muscovite, oligoclase and garnet* and smaller quantities of *potash-feldspar*, protrude large *feldspathic porphyroblasts* or aggregates of well developed feldspathic crystals. The large porphyroblasts are nearly always formed by *oligoclase* while the almond-shaped aggregates, are generally formed of *potash-feldspar* (orthoclase, microcline, microperthite). The laıger crystals enclose muscovite flakes. The fine elements of the matrix are in places compressed and displaced due to the growth of the porphyroblasts.

Biotitic, or more rarely, muscovitic patches, recall those micaceous patches which are formed by thermal metamorphism in some rocks.

54 **PZ-55.** – Banded gneiss with biotite; *on the ridge on the left side of the upper valley.*

This light coloured rock is formed essentially of *quartz* and *feldspars*, while the *micas* form only very thin irregular stripes. Garnet is scarce.

54 **PZ-56.** – Biotite-garnet paragneiss; *on the ridge on the left side of the upper valley.*

These dark and slightly schistose facies, with large crystals of garnet, form fairly extended outcrops in which many beds of amphibolitic gneiss are enclosed.

The main minerals are *quartz, plagioclase* (34-37% An), *biotite* and *garnet.* Elongated black crystals of iron oxide are also frequent.

54 **PZ-57.** – Biotite-garnet augengneiss; *between Kulankae and the ridge on the left side of the upper valley at a height of about 3,500 m (11.500 ft).*

This rock differs from some of the common facies of the Stak formation by the presence of large feldspathic porphyroblasts.

Under the microscope this rock shows many features similar to those already described (lenses and beds of quartz; distribution of the coloured elements etc.) but it is still interesting because of the presence of lenses of equally remarkable dimensions formed of feldspars (for the most part *microperthite* or *orthoclase* and *microcline*, irregular in form and rich in inclusions of *quartz*, *plagioclase*, *muscovite* and *biotite*), or of aggregates of granules of potash-feldspar. Plagioclase is found in lesser quantities.

54 **PZ-58.** – Biotite-garnet-kyanite banded gneiss; *between Kulankae and the ridge on the left side of the upper valley, at a height of about 3,500 m (11.500 ft).*

This sample, formed by alternate light and dark bands and characterized by the remarkable development of *garnet*, corresponds to the more common facies of the formation. The dark bands, formed by *biotite*, *muscovite* and *kyanite* are often displaced by the growth of the garnet poikiloblasts.

53 **PD-20.** – Aplitic garnetiferous gneiss with kyanite; *in the upper Stak valley.*

This rock, very light and mottled by reddish garnets, is formed essentially of *quartz* and *plagioclases* accompanied by smaller quantities of *potash-feldspar*. The feldspars often enclose small roundish granules of quartz.

Well-developed crystals of garnet are numerous. *Kyanite* is present in rather small quantities with its particles always bounded by *muscovite*. Other muscovite is found as independent flakes.

53 **PD-20a.** – Quartzose-feldspathic gneiss with biotite, garnet and kyanite; *at Stak-la.*

This rock is light in colour with small dark discontinuous micaceous streaks. Under the microscope it shows an alternation of very elongated *quartzose beds*, each of which is formed by a few well-developed and crushed particles, and of bands formed by an *aggregate* of rather fine particles of *potash-feldspar* (for the most part microperthite), *plagioclase* and *quartz*.

Some of the feldspar, however, is much developed.

Microperthite is much more abundant than *plagioclase* (oligoclase at 20% An) at the contact with which a *myrmekitic association* is sometimes developed.

Both the feldspars enclose very thin needles of indeterminate nature, visible also in many sialic facies of the Stak gneisses (54 PZ-37, 40). Other larger particles, often prismatically elongated, are recognizable, at least in part, as kyanite.

Small crystals of *kyanite*, better developed than those mentioned above, are found distributed with *biotite*, *muscovite* and *garnet* inside the feldspathic bands.

THE UPPER STAK VALLEY
54 PZ-36→41.

54 **PZ-36.** – Banded gneiss with biotite, muscovite, garnet and kyanite; *lower part of the valley, left side.*

This sample represents a dark band interspersed with light bands of aplitic or pegmatitic appearance.

The rock resembles the 54 PZ-28 type (page 164) collected in the lower Stak valley, but containing smaller quantities of kyanite.

54 **PZ-37.** – Quartzose-feldspathic banded gneiss with kyanite, biotite, muscovite and garnet; *lower trunk of the valley, left side.*

This sample represents one of the light bands alternating with the micaceous-garnetiferous, kyanitic bands 54 PZ-36 type and is in its turn formed by thin irregular and discontinuous lighter and darker bands.

Under the microscope it is seen that defined micaceous beds do not exist. *Muscovite* and *kyanite* are more abundant than in other similar rocks, in such a way that muscovite is more common than *biotite.* It is worth noting that the biotite and kyanite crystals are not always disposed according to the surfaces of schistosity, but can sometimes occur perpendicular to these.

Garnet is present in large poikiloblasts always accompanied by biotite which is often enclosed in them.

Quartz is the most frequent mineral and generally forms long flattened lenses or beds. *Orthoclase* is also abundant as well-developed particles which sometimes enclose quartz.

Plagioclase (15-18% An), also in crystals of remarkable size and with inclusions of muscovitic flakes is rarer.

Very fine needle-like inclusions are frequent in the feldspars. Other prismatically elongated particles correspond to *kyanite,* also present in the form of small enclosed fragments.

54 **PZ-38.** – Biotite-kyanite-garnet-muscovitic banded gneiss with tourmaline; *lower trunk of the valley, left side.*

This sample shows a transition between a dark schistose band, and a light quartzose feldspathic band.

The sialic elements are: *quartz, potash-feldspar* and *plagioclase* 30% An.

The separation between the light and dark bands is very obvious, due to the presence of a thin bed of quartz. Following this is a small feldspathic layer, lacking coloured elements, in which the larger feldspathic particles enclose small granules of quartz, and so besides the quartz (in thin beds enclosed in the feldspathic aggregate, rich in myrmekite), small quantities of biotite, muscovite and garnet begin to appear. *Kyanite* is here very abundant, more so than in the micaceous band.

54 **PZ-39.** – Biotite-muscovite-kyanite-garnet banded gneiss; *lower trunk of the valley, left side.*

In this rock the light and dark bands fade into each other. Otherwise it is not very different from the banded gneisses already described. *Kyanite* is present both in the light and dark portions.

54 **PZ-40.** – Pegmatitic gneiss with tourmaline, garnet and kyanite; *lower trunk of the valley, left side.*

These pegmatitic gneisses are concordant with the banded gneisses.

The fundamental minerals are *quartz* (the most common) *potash-feldspar* (orthoclase and sanidine) and *plagioclases* 20% An.

Also in this rock the quartz forms coarse lenses elongated according to the schistosity; smaller granules of quartz are sometimes enclosed in the feldspars.

Among these sialic minerals *tourmaline*, *garnet* and *kyanite* occur. The *tourmaline* is more frequent in belts parallel to the general foliation of the rock. The *kyanite* is often transformed into muscovite; first a thin irregular border of sericite is formed around the crystals, then the transformation proceeds towards the inside until it is completed by the contemporaneous recrystallization of the sericite into muscovite.

It has been observed that when kyanite is enclosed in quartz the transformation does not occur; it does occur, however, when it is in contact with feldspar. Needle-like inclusions in the feldspars, sometimes attributable to kyanite, are common.

54 **PZ-41.** – Banded gneiss with quartzose-feldspathic bands and bands of biotite, muscovite, garnet and kyanite; *south-east of Kulankae at a height of about 3,600 m (12.000 ft).*

This sample is formed of thin light and grey-violet bands very irregularly developed and with few definite limits. On the whole they are not very different from those observed in the lower Stak valley. Gneissic rocks of this type alternate with other darker rocks which are not very feldspathic but are rather fine-grained 54 PZ-42 type.

Microscopic observations show that the *quartz* does not occur as large particles (as in the rocks of the lower valley, in which alone they form beds or lenses) but as medium-grained granules. It is the most abundant sialic mineral whilst *potash-feldspar* and *oligoclase* ($n\gamma = \omega$ of quartz) are scarce and occur as small patches or isolated particles.

Reddish *biotite* is present in almost the same quantities as *muscovite*. *Garnet* is abundant, and *kyanite* is also frequent.

Iron ore, and rutile are widespread amongst the subordinate minerals; epidote is more rare.

As a whole the rock has some similarities with the 54 PZ-28 sample (page 164) of the lower valley.

THE ROCKS OF THE ASKORE NALA - TWAR ZONE

THE SURROUNDING ROCKS

54 PZ-18, 54 PZ-66 → 74

54 **PZ-18.** – Fine-grained amphibole-epidote gneiss with calcite; *right side of the Indus river, east of the Mulakor limestones, above Skoyo.*

This sample comes from the belt of schists enclosed between the basic Twar mass and the gneisses with feldspathic porphyroblasts which occurs east of Skoyo. The texture is definitely schistose. The most abundant component is *plagioclase* (*andesine-oligoclase* 30-35% An), which, together with fine-grained granules of quartz, forms the lighter part of the rock.

Also present is a quantity of *potash-feldspar*, often microcline. The *amphibole* is nearly always accompanied by remarkable quantities of *epidote*, also of *ceriferous* type. Biotite is scarce, but *calcite* is frequent and sometimes forms thin beds (or veins concordant with the schistosity).

Besides sphene and iron ore, a scapolite of mizzonitic type also occurs as a subsidiary mineral.

54 **PZ-66.** – Epidote-diopside hornfels; *in the alluvium of the torrent north of Twar.*

This sample must come from the walls which rise above the Twar basin.

Under the microscope the rock shows a coarse grain and crystalloblastic texture. The principal component is *epidote*, always in well-developed crystals and often poikiloblastic. Associated with the epidote in moderate quantities is a *pyroxene* with light pleochroism either colourless or greenish, and with values of $c : \gamma = 42^{\circ}\text{-}43^{\circ}$, which correspond to *diopside-hedenbergite.*

Calcite is abundant, but *quartz* in granules is more scarce. The *plagioclase* present in relatively extended and irregularly distributed patches shows incomplete twinning and is without any defined shape. *Sphene* is common.

54 **PZ-67.** – Fine-grained biotitic gneiss; *in the alluvium of the torrent north of Twar.*

This rock is very schistose due to the orientation of the micas. The principal components in descending order are plagioclases, biotite and quartz, distributed with some uniformity.

The *plagioclases* have composition similar to that of *oligoclase* 20% An ($n_\gamma = \omega$ of the quartz; the angle of extinction in ⊥ zone (010) = 5°-6°). Some of the larger particles enclose small granules of quartz.

Medium sized granules of *quartz* are interspersed with crystals of plagioclase.

Biotite is present both as isolated particles and as thin beds. *Epidote* is common and sometimes has a brown pleochroic core of *allanite*. Also present are *zoisite* and *sphene* often grown together around iron oxide.

54 **PZ-67a.** – Fine-grained biotite-amphibole gneiss; *in the alluvium of the torrent north of Twar.*

This rock has a schistose texture and shows traces of movement. It is formed mainly of biotite and amphibole.

Plagioclase is frequent and corresponds to *oligoclase* at about 25% An.

Quartz is present in rather fine grains, whilst amphibole is represented by green *hornblende.*

Biotite, with pleochroism of rather dark tones is often transformed into a very pleochioic emerald-coloured chlorite.

Clinosoizite, *pistacite* and *allanite* are common.

Zoisite, sphene, apatite and magnetite are found in smaller quantities.

54 **PZ-67b.** – Fine-grained amphibole gneiss; *in the alluvium of the torrent north of Twar.*

This sample has a schistose texture and is formed essentially of amphibole, feldspar and quartz.

Plagioclase is the most abundant mineral and is formed of oligoclase at 20-25% An. *Quartz* is present in small quantities. Amphibole is repiesented by well oriented particles of green *hornblende.*

Sphene, epidote, apatite, and zircon are present in smaller quantities.

54 **PZ-68.** – Amphibole gneiss with sphene; *right side of the Indus river, at a height of about 3,000 m (10.000 ft) north-east of Twar.*

This sample has a slightly accentuated schistosity and it is irregular grain-sized. The most abundant minerals are plagioclase, corresponding to *oligoclase-andesine* 27-30% An ($n\alpha = \omega$ of the quartz; the angle of extinction in zone ⊥

(010) = 9°-12°; negative optic sign), and amphibole, represented by green *hornblende*.

Quartz is rather scarce, whilst *sphene* is very abundant and forms one of the main minerals. Zircon, apatite, magnetite and ilmenite are present in smaller quantities.

54 **PZ-69.** – Amphibole gneiss; *right side of the Indus river, at a height of 3,570 m (11.700 ft) above Mulakor, at the contact with the pyroxene tonalite.*

This rock was found at the contact with the gabbro-tonalitic mass, in a thin belt of schistose rocks evidently penetrated by feldspathic material giving them a more obvious gneissic appearance.

The distribution of the minerals in this rocks is not very uniform and several bands, some richer in femic minerals, some richer in feldspar, can be picked out. Sometimes these are displaced so as to form small lenses and swellings.

This is different from the amphibolic gneisses existing in this zone (54 PZ-67b, 70) by reason of the greater development of the feldspars and above all by their peculiar appearance. These are crystals varying greatly in composition from place to place as can be seen by the fact that in a single particle the extinction occurs by patches. In general they are *plagioclases* irregularly penetrated and replaced by *potash-feldspar*; when the substitution is initial it can be seen that the potash-feldspar is diffused inside the crystals through fine fractures. It is worth noting that the better developed feldspathic particles sometimes enclose small crystals of hornblende.

54 **PZ-70.** – Fine-grained amphibolic gneiss; *right side of the Indus river, at a height of 3,500 m (11.500 ft) in the valley leading to Mulakor.*

This sample represents the most common type of rock occurring in this zone. It is very schistose, with an alternation of very fine lighter and darker beds. On the whole the rock is very dark and very fine grained.

The main minerals are amphibole and plagioclase. The *plagioclases* have 25-30% An and are associated with small quantities of *quartz* granules. In some bands *hornblende* is the only femic mineral, but in others it is accompanied by epidote.

54 **PZ-71.** – Amphibole-biotite schist; *right side of the Indus river at a height of 3,700 m (12.000 ft), in the valley leading to Mulakor.*

This rock is formed of an alternation of greenish amphibolic bands, and grey micaceous-amphibolic bands a few centimetres thick.

The greenish parts are formed by *quartz* and *actinolite*, the grey ones by *quartz*, *biotite* and *antophyllite.*

Quartz is the only sialic component present and it is found either as fine-grained granules with femic minerals, or in large crushed elements which, according to the schistosity, form belts and relatively conspicuous beds.

The *actinolite* has the same pale green pleochroic colours and, in the zone between darker and lighter bands, has grown together parallel to the orthorhombic amphibole of *antophyllitic* type, so that the different optic orientation is immediately visible.

The antophyllite, totally without pleochroism, is found almost exclusively in beds rich in biotite.

54 **PZ-72.** – Actinolite chlorite schists with crystals of spathic carbonate; *right side of the Indus river, at a height of 3,800 m (12.500 ft) in the valley leading to Mulakor.*

This sample, intercalated with the other rocks described, has a characteristic greenish colour and is soft enough to crumble in the hand. Beautiful perfectly rhombohedral crystals of *carbonate* protrude from the green mass formed by small flakes of chlorite and fine needles of *actinolite.*

54 **PZ-73.** – Quartzose feldspathic paragneiss rich in biotite; *in the valley above Mulakor at a heigth of about 3,700 m (12.000 ft).*

This rock forms some intercalations inside the series of the amphibolites. In appearance it is similar to the micaschists.

Under the microscope it is seen to be formed of a matrix of *quartz* and *oligoclase* in almost equal quantities. Small flakes of *biotite* disposed in subparallel planes are uniformly distributed in this matrix. Poikiloblasts of *muscovite* are scarce.

54 **PZ-74.** – Actinolite hornfels; *in the upper part of the valley leading into the Indus river east of Mulakor, at a height of about 3,800 m (12.500 ft).*

This rock represents a particular type of the series of metamorphic rocks which separate the Twar mass from the mass of plagioclase gneisses.

Macroscopically the rocks seen to be formed by an aggregate of greenish needles.

Under the microscope it is seen that the rock is formed mainly of *actinolite* in well-developed crystals (light pleochroism with greenish tones; $c : \gamma = 12^{0}-15^{0}$; positive elongation) among which some *calcite* is found. The calcite is sometimes abundant, and in places, more common than amphibole. Iron oxide is scarce.

THE ROCKS OF THE BASIC MASS

54 PZ-19→23, 54 PZ-62→65

54 PZ-19. – Amphibole gabbro; *right side of the Indus river among the limestones of Mulakor.*

This sample represents one of the more common facies of the femic rocks which have developed at the boundaries of the mass, quite extensively inside the limestones around Mulakor. Their common characteristic is their very exceptional grain and the variability of the relationships between femic and sialic minerals. In this sample the amphibole exhibits elongated forms and the feldspars are extensive.

The essential components are amphibole, epidote, calcite and plagioclase; the texture is crystalloblastic and poikiloblastic.

The *plagioclases* are muddy due to the presence of many sericitic flakes and are difficult to classify, though they should correspond to *labradorite* at about 50% An.

Green *hornblende* has often grown together with *epidote.*

Clinozoisite develops at the boundary between amphibole and plagioclase. In those patches richer in epidote *calcite* is abundant.

Common subsidiary minerals are *sphene*, *quartz*, and iron oxide.

54 PZ-20. – Amphibole gabbro; *on the right side of the Indus river, west of the limestones of Mulakor.*

This sample was taken in an outcrop in which streaks of hornfelses also occur. The grain is rather fine and the colour very dark due to the abundance of amphibole and the scarcity of plagioclases. Some orientation of the femic minerals was noted.

The essential minerals are hornblende, biotite and plagioclases.

The *plagioclases* are sometimes turbid due to the presence of sericite; they correspond to *andesine* 40-45% An.

The amphibole, represented by green *hornblende*, is piesent in well-developed particles and with it is associated *biotite* both in patches and thin elongated beds.

A usually irregularly distributed *scapolite* (*mizzonite*) occurs with some frequency and when enclosed in the plagioclases appears to be in a state of transformation.

Magnetite, apatite and zoisite are found in smaller quantities.

54 **PZ-21.** – Hypersthene gabbrodiorite; *right side of the Indus river between Twar and Steriko, opposite Shoat.* (Analysed rock).

This sample represents the normal type of rock occurring between Twar and Steriko; such rocks are crossed by many sometimes small dykes, mainly of aplitic type.

Macroscopically the rather fine-grained rock resembles the microtonalites more than the gabbrodiorites, in appearance.

The mineralogical composition is characterized by the abundance of plagioclases and by the presence of orthorhombic pyroxene, monoclinic pyroxene, amphibole and biotite, which are the main minerals.

The *plagioclases* form extended patches and are represented by well formed homogeneous particles. Only in some cases there is a very gradual variation from the core to the periphery. From the examination of albite and albite-Carlsbad twins it appears that the composition of these feldspars oscillates between 40% and 48% An.

Allotriomorph potash-feldspar is much scarcer. This for the most part comprises *sanidine* as can be seen from the low value of the angle 2V. More frequent however is *microperthite*, which is sometimes found in patches totally enclosing particles of andesine.

In places myrmekites develop between the plagioclases and potash-feldspar.

Quartz is present in smaller quantities.

Pyroxene is represented by both orthorhombic and monoclinic types nearly always grown together. Generally, but not always, the orthorhombic type occupies the central parts. Often the association is completed by the apperance of hornblende and biotite towards the outer parts.

The orthorhombic pyroxene, with pleocroism α and β = rose, γ = grey greenish, corresponds to *hypersthene.*

The monoclinic pyroxenes (c : γ = 42°-45°; 2V γ = 46°-60°; pleochroism hardly visible on the greenish tones) are of the *augitic* type with a tendency towards terriferous types.

Both in the orthorhombic and monoclinic pyroxenes characteristic reddish inclusions, of lamellar appearance and often orientated in relation to the crystal host, are sometimes observed.

Amphibole is represented by poikiloblastic crystals of green *hornblende* especially in the outer parts or in the smaller particles.

Biotite occurs both in association with the amphibole and as isolated particles. This mineral is also in part poikiloblastic.

Less important minerals include apatite and zircon.

54 **PZ-23.** – Biotite-amphibole orthogneiss with epidote; *right side of the Indus river, two miles west of Steriko.*

This sample represents the schistose facies of the gabbrodiorites and of gabbros which occur in the Twar area in massive facies and which then change westwards into more definitely orientated types.

The texture is crystalloblastic and the femic elements poikiloblastic. The essential components are plagioclase, quartz, green hornblende, biotite and epidote.

The *plagioclase* has the same appearance as the massive facies and also in this rock corresponds to *andesine* 45-47% An. Signs of para- and post-crystalline deformation are evident in its crystals.

Quartz is abundant and is found in lenses parallel to the schistosity of the rock, or in fine-grained granules in those patches rich in femic minerals.

The femic elements form irregular beds which delimit large lenses of sialic minerals. Biotite sometimes forms isolated patches, but has sometimes grown together with the *hornblende* which is nearly always poikiloblastic.

Epidote and *apatite* are relatively frequent. At the edges of some crystals of plagioclase are found very fine acicular aggregates similar to sillimanite which are not very well defined.

54 **PZ-62.** – Amphibole gabbrodiorite; *right side of the Indus river, between lower Steriko and middle Steriko.* (Analysed rock).

This sample represents the most common type met in this zone. The rock is of medium or medium-fine grain and exhibits a slight orientation of its mineralogical components. This orientation is perhaps more evident in the outcrops.

The main minerals are the plagioclases, amphibole, epidote and biotite. In texture it resembles a metamorphic rather than an igneous rock.

The *plagioclases* occur as well-developed crystals, of homogeneous composition; only in some cases the border is of more sodic type. In the latter the central part is formed of *andesine* 42-45% An, and the periphery of *andesine oligoclase* at 30-35% An. Better-developed xenomorph particles, enclosing swarms of euhedral crystallines of epidote, are rare.

Potash-feldspar is scarce and is represented by *microperthite.*

Myrmekitic associations are rather rare as too is *quartz*, which is always associated with femic minerals.

Amphibole is formed by common *hornblende* with pleochroism from yellow brown to intense green, or bluish green. This is poikilitic due to inclusions of quartz or can be found in aggregates of fine-grained granules.

The amphibole is nearly always associated with *biotite* and *epidote.* The epidote is often poikiloblastic and also appears in well-developed particles.

54 **PZ-63.** – Hypersthene gabbrodiorite; *right side of the Indus river, between higher Steriko and Lustung, at a height of about 2,400 m (8.000 ft).*

This sample was taken in the broad valley which leads from Steriko to the plain where the village of Lustung is situated. Macroscopically this type appears finer and lighter than the one between lower Steriko and middle Steriko (54 PZ-62). A slight orientation of the femic minerals is evident.

The principal constituents are plagioclases and pyroxenes, while quartz, amphibole and biotite are present in smaller quantities.

The plagioclases are found in crystals for the most part elongated in one direction, and have a homogeneous composition, which corresponds in the different particles analysed to *labradoritic-andesine* 46-50% An. Some particles show evidence of the sorting of potash-feldspar. This latter is *antiperthite* with which smaller quantities of perthites are associated.

Quartz and potash feldspar are scarce; the quartz is always in very fine-grained granules.

The pyroxenes are represented both by orthorhombic and by monoclinic terms which have often grown together and are sometimes also associated with *amphibole* and *biotite*, as has been seen in the rock gathered opposite Shoat (54 PZ-21).

The orthorhombic pyroxene is of *hypersthenic* type; the monoclinic pyroxene corresponds to an *augite.*

Green hornblende and biotite, both rather scarce, can occur as distinct crystals, but more often they are associated showing interdependent connections. Poikiloblastesis is not common.

Among the less important minerals magnetite, zoisite, and apatite should be noted.

54 **PZ-64.** – Amphibole-pyroxene gabbro; *right side of the Indus river, between higher Steriko and Lustung, at a height of about 2,600 m (8.500 ft).*

This sample corresponds to a particular coarse-grained amphibolic-feldspathic type, with a granular olocrystalline texture, enclosed in the rocks described above (54 PZ-63).

The fundamental components are the plagioclases, amphiboles, and pyroxenes.

The *plagioclases* in form and disposition are similar to those of the other rocks of this mass, but are remarkably richer in An, from 60% to 85% An, thus corresponding to labradoritic and bitownitic mixtures.

The *pyroxene* is of augitic type and sometimes shows slight uralitization at the edges.

Green *hornblende* often forms large patches and *biotite* is associated with it in small quantities.

54 **PZ-65.** – Hornblende-biotite-pyroxene tonalite; *in the valley east of the village of Twar* (Analysed rock).

This sample is representative of the acid type of the mass, developed mainly in its higher and eastern part.

The texture is characterized by poikiloblasts of hornblende, the main femic mineral; other minerals which accompany it are biotite and pyroxene.

Among the sialic minerals the plagioclases predominate; but potash-feldspar and quartz are also quite important.

On the whole the rock is quite similar to the one gathered above lower Steriko.

The *plagioclases* are formed by *andesine* 40-45% An, with weak zoning but more accentuated than in other rocks.

Fractures and deviations of the lamellae of twinning are relatively common and correspond to para-or postcrystalline deformations.

Potash-feldspar is always found in perthitic associations and is often isolated from the belts of quartz and plagioclase.

Myrmekites and *quartz* which is often enclosed in the femic minerals, are relatively abundant.

Augitic pyroxene is not very abundant and always forms the cores of crystals which change towards the outside into green *hornblende.* This change is sometimes gradual, more often discontinuous, so that the pyroxene appears to be surrounded by a very poikiloblastic amphibole.

The *hornblende*, also in small crystals, is always poikiloblastic and nearly always more so at the centre than at the periphery. The development of this amphibole generally occurs in a quartzose matrix.

Large flakes of *biotite* are generally associated with the amphibole.

Other minerals are magnetite, zircon, common epidote, orthite, zoisite and apatite.

THE ROCKS ENCLOSED IN THE BASIC MASS

54 PZ-22, 24, 24a, 24b.

54 PZ-22. – Amphibole hornfels with scapolite; *right side of the Indus river, a little east of Steriko.*

This sample represents the most common facies of the numerous dark patches enclosed in the basic rocks of gabbroic type. Its colour is very dark, almost black, and its grain is very fine. Schistosity is not observed either macroscopically or under the microscope; the texture is crystalloblastic.

The amphibole represents nearly 70% of the rock; among the other minerals scapolite is abundant, while biotite and plagioclases are present in smaller quantity.

The plagioclases, scarce and of small size, correspond to *andesinic-labradoritic* mixtures 45-50% An.

Green *hornblende* is found in small rather thick-set crystals. More abundant than *biotite* is *scapolite* which by its optic characteristics (index of refraction between 1,552 and 1,577) is seen to correspond to a *mizzonite*, although having some difference of composition from particle to particle.

Epidote is frequent. A fairly widespread secondary mineral is *rutile*, but sphene is scarce.

54 PZ-24. – Amphibole-epidote gneiss with scapolite; *on the right side of the Indus river, about 3 km west of Steriko.*

This sample corresponding to part of a belt enclosed in the metamorphic basic rocks (54 PZ-23) exhibits an obvious schistose texture and is of dark colour due to the abundance of femic minerals.

The essential components are amphibole, plagioclases and epidote.

The *plagioclases* have the same appearance as those seen in the rocks of the basic mass and correspond to *andesine* 40% An.

The amphibole is represented, as usual, by green *hornblende* in orientated particles. Also widespread is *epidote* which sometimes shows a pleochroism from rose-yellow to violet. These are manganesiferous types, and sometimes enclose small irregular particles of biotite.

Scapolite is rather scarce and not usually uniformly distributed. Mizzonite appears as dismembered and, in part, sericitized particles in the feldspathic patches. Small granules of quartz are scarce but *sphene* is common.

54 **PZ-24a.** – Amphibole-biotite gneiss with scapolite; *right side of the Indus river, 3 km west of Steriko.*

This sample was taken from the same belt of rock as the 54 PZ-24 sample, from which it differs only by the fact that some bands with different composition can be distinguished. One band is formed essentially of *amphibole, biotite, scapolite* (mizzonite) and *epidote,* feldspar being almost totally missing. This is followed by a thinner band formed almost exclusively of *plagioclase* and *quartz* and finally another larger band which differs from the first by the relative abundance of *plagioclase.*

The plagioclase seems a little more sodic than usual (about 30% An).

54 **PZ-24b.** – Scapolite-amphibole-biotite hornfels with epidote; *on the right side of the Indus river, 3 km west of Steriko.*

This sample also comes from the same inclusion as samples 54 PZ-24 and 54 PZ-24a, but it is easily distinguished from these by the scarcity of plagioclase, though it is very similar to sample 54 PZ-22 (rock enclosed in the gabbros E of Steriko).

The main mineral is *scapolite*; *amphibole* and *biotite* are nearly always associated with each other. *Epidote* can enclose all the minerals now mentioned and in some cases is a little ceriferous.

THE ROCKS OF THE ASKORE VALLEY

54 PZ-26, 34, 35.

54 **PZ-26.** – Amphibole-epidote-biotite gneiss; *right side of the Askore valley, near the mouth.*

Macroscopically this rock exhibits a definite schistosity and an alternation of lighter and darker bands, but under the microscope the minerals do not seem to be so decidedly orientated.

The principal components are *plagioclases*, *amphiboles*, *biotite* and *epidote*.

The *plagioclases*, variously twinned, correspond to 30-35% An and sometimes enclose granules of quartz. Other quartz is interposed among the different plagioclase particles.

Apatite is common.

54 **PZ-34.** – Garnet-epidote amphibolite with scapolite; *right side of the Askore valley, at a height of about 3,600 m (12.000 ft).*

This slightly schistose and very dark sample has a medium or medium-coarse grain and is spotted by granules of feldspar.

The *plagioclases*, in subordinate quantities in relation to the total of the femic minerals, are represented by *andesine* about 40% and with them is associated some quartz, for the most part in granules, but also in small lenses.

Hornblende, *garnet* and *epidote* are often strictly associated. Garnet, in large particles, and epidote are sometimes very slightly poikiloblastic. Together with these minerals occur modest quantities of a *scapolite* corresponding to *mizzonite*.

Among the other minerals yellowish granules of *rutile* are frequent.

54 **PZ-35.** – Hornblende-garnet schist with epidote; *right side of the Askore valley at a height of about 3,600 m (12.000 ft).*

This rock is almost totally black due to the abundance of thick-set well-developed crystals of amphibole. Reddish garnet sometimes forms large isolated particles, sometimes streaks of fine-grained minerals. Patches and thin light beds of quartz are rare. Rocks of this type form small masses inside the amphibolites similar to the 54 PZ-34 sample.

Microscopic examination confirms that the rock is formed almost exclusively of green *hornblende* and *garnet*, with associated small quantities of *epidote*.

The sialic minerals are represented by small quantities of *quartz*, sometimes in small lenses or independent granules, more often enclosed in the poikiloblastic crystals of the femic components.

Rutile granules are common.

THE ROCKS OF THE RIGHT SIDE OF THE INDUS RIVER, BETWEEN THE MOUTH OF THE TURMIK VALLEY AND SKOYO

THE ROCKS OF THE PLAGIOCLASIC GNEISSIC MASS

54 PZ-17, 75, 75a, 76, 92.

54 **PZ-17.** – Porphyroblastic plagioclase gneiss; *west of Dasu, near the eastern boundary of the plagioclasic gneissic mass, along the Skardu-Gilgit caravan-trail.* (Analysed rock).

This sample was gathered in the belt of transition between the plagioclase gneisses and the surrounding rocks, and represents the more common type of the plagioclase gneisses occurring in this part of the mass. Enclosed in these rocks are streaks of fine-grained biotite-epidote gneisses (54 PZ-17 a), and it is just neaı one of these streaks that the sample in question has been taken.

In the field the rock appears schistose due to the orientation of the femic minerals, though the feldspathic porphyroblasts do not show a well definite orientation.

The crystalloblastic texture of the rock and the usually irregular distribution of the mineralogical components (plagioclases, quartz, biotite, epidote and muscovite) can be seen under the microscope.

The large plagioclases are separated by a relatively fine-grained aggregate, formed by the other minerals.

Quartz may be present in large individuals, or small crystals in the fine-grained aggregate rich in feldspar.

The large individuals of quartz form patches which partially surround some plagioclasic porphyroblasts or extend, in the form of small veins of irregular trend and thickness, into the feldspathic-micaceous aggregate, from which they are quite distinctly separated. They nearly always have parallel portions with an irregular extinction, and are always elongated in a direction slightly away from ε'.

In the fine-grained aggregate, one finds together with granules of quartz, small crystals of a very sodic plagioclase (generally but not always with a positive optic sign), with poorly defined boundaries between one particles and another.

Biotite, in well-developed flakes, is relatively abundant and *muscovite*, also in large sheets, has often grown together with it.

Epidote, corresponding to a slightly ferriferous type (strong birefringence, sometimes light pleochroism) is nearly always associated with biotite, in granules of different dimensions.

At the edges of the biotite very fine-grained crystallines of sphene are often found. The associations of biotite and epidote are sometimes accompanied by granules of calcite spotted with iron oxide. When calcite is present the biotite exhibits an initial process of chloritization.

The *plagioclasic porphyroblasts* do not exhibit well-defined crystalline limits and could be compared to patches of irregular shape formed by the amalgamation of different particles. These in their turn lack definite crystalline limits, and sometimes have an orientation which is a little different from one to another. In some cases streaks of quartz, sometimes accompanied by a little biotite and epidote, are interposed between the different parts of a feldspathic patch, each having a different orientation.

The composition of the plagioclases oscillates between 15% and 20% An ($n\beta < \omega$ of the quartz; $n\gamma$ a little higher than ω of the quartz; negative optic sign, which in a few cases is positive at the border) and the zoning is absent or indistinct.

Other minerals are enclosed in all the plagioclasic porphyroblasts. These for the most part are *muscovite* and *epidote*, but also common are *biotite* and *quartz*. Generally the finer-grained crystals of muscovite and epidote show a definite orientation in the plagioclase, while the larger crystals of these two minerals and the biotite do not show a disposition relating to the crystallographic direction of the plagioclase.

The *inclusions of biotite* often show a progressive decrease of pleochroism and of birefringence. The *inclusions of quartz* are generally reabsorded; some of them show a characteristic zig-zag form in relation to those edges which intersect the planes of composition of the twinned plagioclases. Only very rarely small slightly more sodic plagioclases enclosed in the larger crystals of plagioclase have been observed.

Notwithstanding the presence of inclusions, the plagioclases are always clear.

Some signs of postcrystalline deformation, micas and epidotes with slightly bent planes of cleavage have been observed in the rock.

54 **PZ-75.** – Porphyroblastic plagioclase gneiss; *western part of the plagioclasic gneissic mass, at a height of about 3,900 m (13.000 ft).* (Analysed rock).

This sample has been taken in the highest outcrops of the mass, several hundred metres from the northern contact with the surrounding rocks, which are here represented by dark fine-grained amphibolites In this locality the outcrops are confined to spurs emerging from the covering scree and to clefts cut by torrents. In the latter it can be seen that rocks similar to that under study pass into other facies richer in amphibole (54 PZ-75a) and include small, almost exlusively amphibolic bands.

This rock does not differ much in appearance from the one gathered near Dasu (54 PZ-17); it is only slightly darker and exhibits a greater development of feldspathic porphyroblasts.

Microscopic observation shows that the most important difference is the presence of small quantities of *amphibole* among the femic components. Some characters already described in connection with the rock gathered in the eastern outcrops (the presence of streaks of quartz in the plagioclasic porphyroblasts etc.) are even more evident in this rock.

The *feldspathic porphyroblasts* sometimes enclose smaller particles of plagioclase, of slightly different composition, and distinguishable by the absence or scarcity of inclusions and by the fact that they are often associated.

Among the inclusions in large plagioclases, of the same type, *biotite* and *hornblende* are sometimes remarkably frequent. After the loss of pleochroism and colour of both these minerals, they can be distinguished by the values of the angle of extinction $c : \gamma$ ($z \wedge c$) and when it is measurable, by the value of the angle 2V. Generally these femic inclusions are better developed and show small modifications of their optic characteristics more at the edges of the porphyroblasts than at the core.

In some cases complete aggregates of biotite, hornblende and epidote are enclosed.

Sphene is frequent among the subsidiary minerals.

54 **PZ-75a.** – Porphyroblastic plagioclase-amphibole gneiss; *western part of the plagioclasic gneissic mass, at a height of about 3,900 m 13.000 ft).*

This rock comes from the same zone as sample 54 PZ-75. The thickness of the scree makes difficult to establish if biotitic-amphibolic or almost exclusively amphibolic types predominate. These rocks enclose lenses or patches of dark material, very rich in amphibole.

Macroscopically the sample is distinguished from others representative of the plagioclasic gneissic mass by a darker colour due to the abundance of femic elements.

Microscopic examination shows additional differences to the other rocks, i. e. the richness in *amphibole*, the scarcity of *biotite* (crystallized with the hornblende) and of *epidote*; also *quartz* is much more scarce.

Besides *plagioclasic porphyroblasts* of the same type, large patches formed by *aggregates of fine-grained crystals of plagioclase* are present. In these the limits between one particle and another are indistinct and each has a slightly different orientation. Enclosed in this particular aggregate are remarkable quantities of *muscovite* and *epidote* in a way similar to that observed in the common porphyroblasts, except that in this case the inclusions are not oriented.

In other cases similar feldspathic patches have a fairly large central part, occupied by a porphyroblastic plagioclase which fades away into the fine-grained aggregate.

The largest plagioclases enclose long muscovitic flakes which sometimes extend out of the plagioclasic crystals and cross particles of different orientation. The only femic inclusions is *amphibole*, present in different stages of transformation.

54 PZ-76. - Porphyroblastic plagioclase-biotite gneiss; *central part of the plagioclasic gneissic mass, at a height of about 3,900 m (13.000 ft)*.

This sample was taken about one kilometre east of samples 54 PZ-75 and 54 PZ-75a, on the right (western) side of the larger valley which, having cut into the mass of plagioclase gneisses, leads to the Indus River. The exact location of the sample is in the higher part of this valley, where the rocks become so steep that they form a nearly continuous wall. Enclosed in these rocks together with large feldspars are bands of paraschists, especially the arenaceous types (54 PZ-77).

Macroscopically the rock is closely similar to sample 54 PZ-17.

This similarity is also confirmed under the microscope. The most important difference is the presence of a small quantity of green *hornblende*, constantly associated with *biotite* and *epidote*.

The plagioclasic porphyroblasts sometimes have a great abundance, sometimes a scarcity of inclusions. It has been seen that in some feldspathic patches, formed by the amalgamation of many particles distinguishable only by their different orientation, one particle can be very rich in inclusions and the one near to it almost devoid of inclusions, or the same particle can have portions containing very different quantities of inclusions (e. g. the core free and the periphery rich in inclusions and vice-versa).

Between the inclusions quartz is always very scarce.

54 **PZ-92.** – Porphyroblastic plagioclase-biotite gneiss; *right side of Turmik valley, west of Buripa, near the boundary.* (Analysed rock).

This sample, distinguished from the others by the scarcity of coloured minerals, by the lack of visible schistosity and by the absence of large porphyroblasts, was taken near the boundary, at about the height of the village of Buripa, on the valley walls facing the morainic ridge leading to Dasu which runs parallel to the Turmik valley.

This facies alternates with the most common type of plagioclase gneisses while however remaining limited to the most peripheral part of the mass. In its light colour it resembles some of the granites or leucogranites.

Microscopic observation reveals petrographic features perfectly similar to those described for the other rocks of the plagioclasic mass.

The plagioclase seems, on the whole, to have a slightly more sodic composition than in the other rocks (optic sign for the most part positive, $n\gamma \leq \omega$ of the quartz.).

Large crystalloblastic and poikiloblastic flakes of *muscovite* between the porphyroblastic inclusions cross undisturbed particles of different orientation, and also particles of different nature. Often associated with the muscovite is *biotite*, also with flakes of remarkable dimensions and similar characteristics.

ROCKS OF THE AGMATITIC BELT AND ROCKS ENCLOSED IN THE PLAGIOCLASIC GNEISSIC MASS

54 PZ-16, 17a, 77→82

54 **PZ-16.** – Fine-grained biotite-epidote gneiss with plagioclasic porphyroblasts; *west of Dasu, in the outermost part of the agmatitic belt.* (Analysed rock).

This sample was taken in the outermost part of the agmatitic belt, where the « granitoid » rocks are represented only by an interlacing of dykes inside the surrounding rocks, formed mainly of fine-grained biotite-epidote gneisses.

In the field the rock shows a dyke form and is concordant with the surrounding fine-grained gneisses and has a schistosity concordant with that of the surrounding rocks. Its appearance is porphyric due to the presence of large plagioclases whose number and dimensions vary from place to place.

Under the microscope it can be seen that the rock is characterized by the development of *plagioclasic porphyroblasts* on a groundmass of rather fine grain. This groundmass, which forms about 70% of the rock, has characteristics similar to those met in the biotite-epidote gneisses of the surrounding formation (54 PZ-17a). However, it has a less uniform orientation of the micas and different quantitative ratio between biotite and muscovite. The less uniform schistose texture is above all due to the growth of feldspathic porphyroblasts, which have compressed and displaced, in different ways, the minerals in which they have developed. It is however in part due to the un-orientated disposition of the neoformed *muscovite*, which is here much more abundant than in the surrounding gneisses, although having the same characteristics (remarkable development of the flakes, poikiloblastesis etc.). In some cases it seems that muscovite also forms at the expense of biotite.

In the groundmass biotite and muscovite are accompanied by *epidote*, while the sialic minerals are represented by *quartz* and by granules of very *sodic plagioclase*.

The *plagioclasic porphyroblasts* have a different composition from the plagioclasic granoblasts of the groundmass, corresponding on the average to mixtures at 20-25% An ($n\beta = \omega$ of the quartz; $n\gamma \cong \varepsilon$ of the quartz; negative optic sign). They sometimes have a slight zoning, either continuous or rhythmic, but with variations of composition which are hard to recognize.

These porphyroblasts correspond perfectly to those observed and described in the plagioclase gneisses outcropping W of this sample (irregular and indefinite limits, richness in inclusions of muscovite, epidote, quartz, biotite etc.); therefore see the descriptions of these (54 PZ-17; 54 PZ-75).

54 **PZ-17a.** – Biotite-epidote fine-grained gneiss; *west of Dasu, at the eastern limit of the gneissic plagioclasic mass* (Analysed rock).

This sample was taken from a large patch of dark schists enclosed in the plagioclasic porphyroblasts (54 PZ-17 type).

The essential minerals of this rock are: biotite, epidote, quartz and albite, in uniformly distributed small particles.

The texture is clearly schistose due to the orientated disposition of the micas, represented wholly by biotite.

Much more rare is *muscovite*, present as well-developed distinctly poikiloblastic flakes, sometimes disposed in a direction parallel or subparallel to the lepidoblasts of biotite, while at other times showing no defined orientation, but occurring across or perpendicular to the other micaceous particles.

Epidote is abundant and is distributed as small equal-sized granules. These are formed of slightly ferriferous mixtures (light pleochroism and high colours of interfercence).

The sialic minerals, *quartz* and *plagioclase*, are present in rather fine-grained granoblasts always perfectly clear and devoid of inclusions. The *plagioclase* corresponds to very *sodic* types (very low indices of refraction; optic sign always positive). Only in rare cases have I picked out grains corresponding to albitic-oligoclasic mixtures with an An content definitely higher than 10% An.

Among the subsidiary minerals are sphene and some crystals of apatite and zircon.

54 **PZ-77**. – Quartzose-feldspathic fine-grained gneiss with biotite and epidote; *central northern part of the plagioclasic gneissic mass, at a height of about 3,900 m (13.000 ft).*

This sample was taken on the right side of the large valley leading down to the Indus River which cuts into the mass of plagioclase gneisses. The sample comes from large bands of fine-grained gneisses, which interrupt the continuity of this granitoid mass. They in fact form large elongated bands enclosed in the granitoid gneisses (54 PZ-76) type (page 191) and are represented by the alternation of greenish rocks (very epidotic schists) and light rocks, of arenaceous aspect. Also associated perhaps are some fine-grained acicular amphibolites which have not yet been observed here.

The sample under study corresponds to the lighter beds and macroscopically could resemble fine-grained aplite.

Under the microscope the rock seems to be formed of a fine-grained aggregate of *albite* (or albite-oligoclase) and of *quartz* with which are associated micas and epidote, always in small particles.

The grain size of the quartzose-feldspathic matrix is not very homogeneous, because the finer zones are associated with patches of better-developed crystals. Often only the granules of quartz posses well defined limits, while the plagioclasic particles seem to fade one into the other. Some patches are formed of an aggregate of better-developed plagioclasic particles (but still very different from the plagioclasic porphyroblasts which characterize the granitoid gneisses).

Biotite, in small flakes, is very often chloritized. Much more abundant than this is the *light mica* which, in very thin elongated particles, is widespread throughout the rock, without showing any defined orientation.

Since some muscovitic flakes have a weak greenish colour, it is not impossible that part of the light mica has been formed by the transformation of biotite.

The *muscovite* is also present with larger poikiloblastic particles, similar to those observed in the fine-grained biotite epidote gneisses of the surrounding formation (54 PZ-17a).

Epidote is also present with poikiloblastic crystals.

Among the subsidiary minerals one finds granules of apatite. Calcite is localized in some bands of the rock.

54 **PZ-78.** – Quartzose-feldspathic fine-grained gneiss with epidote, biotite and hornblende; *in the valley west of Dasu, at a height of about 2,800 m (9.000 ft), at the limit of the granitoid mass.*

This sample was taken in the narrow valley directly W of Dasu, in a zone corresponding to the agmatitic belt which divides the granitoid mass from the surrounding rocks. Here the granitoid rock has a slightly finer grain than in other places and its relation to the sample under study is not very clear. It can however be said that the rock under examination has the appearance of an inclusion many metres in length.

Because of its light appearance and fine grain it resembles the 54 PZ-77 sample (this is also enclosed in the granitoid gneisses), but has a more evident schistosity. Under microscopic observation, it still differs due to the more typically arenaceous structure and the greater richness in quartz.

The mineral particles which form the fundamental *quartzose-feldspathic aggregate* are easily distinguishable and of equal size, but here and there localized patches formed by the association of a few much better developed particles are present. These are completely without idiomorphism and, at the edges, enclose granules of the fundamental aggregate. It does not seem that remarkable differences of composition exist between the large and small plagioclases. Both have a content fluctuating between 15% and 20% An ($n\gamma < \omega$ of the quartz; negative optic sign) and rarely lower than 15% An (positive optic sign).

In the patches with better-developed plagioclases, and only in these, *muscovitic* flakes are characteristic. These are variously intersected and accompanied by a variable quantity of epidote.

The clear poikiloblastesis of the flakes of muscovite, which often have a skeleton-like appearance, is worth noting. This also occurs when the isolated particles of the light mica are found in the fundamental aggregate. The same can also be said of the epidote.

The rock is dotted by a relatively abundant quantity of granules of *epidote*, but poikiloblastic *amphibole* and *biotite* are scarcer.

54 **PZ-79.** – Biotite-epidote fine-grained gneiss with plagioclasic porphyroblasts; *in the valley west of Dasu, at a height of about 2,800 m (9.000 ft), at the limit of the granitoid mass.*

The location of this sample is near that of the 54 PZ-78 sample also enclosed in granitoid gneisses. In the field it has not been possible to definitely establish if it is a real inclusion or a dyke with some schistosity.

Macroscopically the rock resembles a microgranite or a microgranodiorite with a slightly uniform texture, patched by better-developed feldspars and, here and there, by large biotites. Dark biotitic lenses, not very well defined but clearly schistose, are very frequent.

Under the microscope it is seen that the main structural feature of the rock is the presence of medium-sized feldspathic porphyroblasts developed on a fine-grained granoblastic matrix.

The analogy with the 54 PZ-16 sample (which was taken in a dyke between the fine-grained contact gneisses and to which the present sample has no very great macroscopic similarity) is perfect (see the description at page 192). The only difference seen is the presence in the rock under study of small quantities of *hornblende*, together with the biotite.

54 **PZ-80.** – Actinolite schists with phengite porphyroblasts; *in the valley west of Dasu at a height of about 2,500 m (8.000 ft).*

This sample comes from one of the bands enclosed in the granitoid gneisses.

Macroscopically the rock appears to be an aggregate of greenish needles between which emerald-coloured micaceous flakes protrude.

Under the microscope it is seen that the rock is formed almost completely of small acicular amphiboles with slight pleochroism towards greenish colours, referable to *actinolite* (positive elongation, negative optic sign; $c : \gamma = 16^{o}$).

Large particles of micaceous minerals are developed on the amphibolic matrix. Refraction indices between 1.58 and 1.60, the value $2V_{\alpha} = 20^{o} - 40^{o}$ and the very high birefraction indicate that this is a mica of the *muscovite* series, maybe *picrophengite*.

These large micas are always poikiloblastic due to inclusions of needles of actinolite disposed as sheaves and intersecting themselves. Here and there patches of spatic *carbonate* are present, and because of this the rock can be considered as a calciphyre with a low content in carbonates.

Plagioclases of albitic type are scarce. These are plunged into the amphibolic aggregate and enclose needles of actinolite.

54 **PZ-81.** - Actinolite schist; *enclosed in the plagioclase gneisses, in the valley west of Dasu.*

This rock, light green in colour, is formed by a thin interlacing of elongated acicular particles of actinolite associated in belts intersecting each other and of such a size as to be easily seen with the naked eye.

In some irregularly distributed patches dark micaceous flakes are present.

54 **PZ-82.** - Talc schist with pyrite; *enclosed in the plagioclase gneisses, in the valley west of Dasu.*

This rock has a clearly schistose texture due to the orientated disposition of the thin flakes of talc. On the light matrix of the rock crystals of *pyrite* with a maximum diameter of 1 cm can be seen.

THE ROCKS OF THE TURMIK-INDUS AREA

THE ROCKS OF THE INDUS VALLEY (BETWEEN KATZARAH AND THE ENTRANCE OF THE TURMIK VALLEY)

54 PZ-1→15; 53 PD-2→6, 9, 12→15

54 **PZ-1.** – Labradorite-biotite-sillimanite gneiss with garnet; *near the Katzarah lake, on the left side of the Indus river.*

The rock is characterized by the presence of numerous indipendent flakes of biotite, rather uniformly distributed in an ash-grey background. On the outcrops we can recognize a little accentuated schistosity, which therefore is not clearly individuated in a single sample.

Under the microscope the ash-grey portion results constituted of a *quartz* and *plagioclase* aggregate, in which either the first or the second prevails. Generally the quartzose portions are constituted of little more developed individuals.

Plagioclase, which corresponds to rather calcic members (*labradorite-bitownite*), has a very variable composition and sometimes only is twinned.

Biotite is the most abundant mafic mineral in the rock; its well-developed flakes are differently associated one to the other and show no definite orientation. Biotite is generally altered into sillimanite at the edges and often also in the core of its crystals; the alteration produces the separation of iron ores grains.

With biotite are associated also some *muscovite* flakes: the white mica is present with very poikiloblastic crystals of notable dimensions, which are sometimes partially altered into sillimanite.

The *sillimanite* is present in such a quantity to be considered as a fundamental component of the rock; the needles, of various dimensions, are combined in bundles and sheaves; the mineral seldom appears with isolated individuals.

Small quantities of *garnet* and *tourmaline* are present.

54 **PZ-2.** – Aplite with garnet; *right side of the Indus valley to the south-east of Tsordas.*

The sample has been taken from a leucocratic dike unconformably crossing the schists, which constitute the rocks prevailing in this area. In the outer parts this dyke has rather fine grain, which increases towards the inner parts, assuming a pegmatitic appearance. The sample corresponds to its fine-grained portion.

The main components of this rock are *K-feldspar* and *quartz* in roughly equidimensional individuals. K-feldspar is very often present as *microline*, seldom as orthoclase, microperthite and microcline-perthite.

Plagioclase, with *albite-oligoclase* composition (10-15% An), is present in small quantities and sometimes, when put into contact with microcline, shows a more or less developed myrmekitic shell.

Small quantities of *biotite* and *muscovite* are always present with poikiloblastic or even skeletal crystals.

Garnet individuals are rare and very large.

Epidote and calcite are present as accessories minerals.

54 **PZ-3.** – Amphibole diorite gneiss; *right side of the Indus valley, in front of Basha.*

The rock has the aspect of a diorite or of a slightly oriented, medium-grained tonalite; its colour varies from a lighter to a darker tone.

Under the microscope it shows a schistose structure because of the suboriented disposition of micas, amphibole, plagioclase.

Plagioclase, the average composition of which is *oligoclase-andesine* (30% An), is often present as twinned and elongated crystals, which are oriented mostly according to the schistosity of the rock; in the same way as it has been seen in the basic rocks of Twar, the composition planes of the twinned crystals are disposed according to the schistosity surfaces. The composition, on the whole, is rather uniform, but there are local variations patchy distributed. Sometimes in the crystal cores some evanescent portions, probably due to reabsorption of original feldpars, are visible; in some cases K-feldspar portions can be seen.

Some plagioclase grains enclose biotite, hornblende and apatite individuals.

Biotite and *hornblende* are present as either isolated or generally associated and intergrown crystals.

Amphibole is quite often extremely poikiloblastic because of the presence of numerous quartz inclusions.

Quarz, if any, is always interstitial.

54 **PZ-3a.** – Fine-grained amphibole-biotite gneiss; *right side of the Indus valley, in front of Basha.*

The hand-specimen is fine-grained and dark-grey coloured with small blackish patches.

Under the microscope the rock results constituted of the same minerals described for the sample 54 PZ-3, with the exception of quartz, which is in a very small quantity here. On the contrary the texture is different: *plagioclase* forms a granular aggregate with no definite orientation, whereas *biotite* is present as fine flakes and *amphibole* is crystalloblastic, but never poikiloblastic.

Plagioclase almost often encloses some needles which are so thin that it is impossible to determine their optical characters; as in some cases this mineral shows a slight pleochroism with green tones and inclined extinction, it might be an actinolitic amphibole.

Sphene is present as an accessory mineral.

54 PZ-4. – Pyroxene-amphibole-biotite gabbrodiorite; *right side of the Indus valley, about 3 km below Basha, in the scree.*

The medium-fine-grained rock, showing a slight schistose structure, is like the basic rocks outcroping in the area between the Twar valley and Steriko (54 PZ-21).

Under the microscope the similarity with the basic rocks of Twar is confirmed too. The essential components are plagioclase, pyroxene, biotite and amphibole; quartz is in much smaller quantities. The never altered and rather homogenous *plagioclase* crystals enclose small individuals of mafic minerals and iron ores grains.

Pyroxene being always an *augite* does not enclose the dark « schiller » characteristic of the basic rocks of Twar; its crystals are quite always partially altered into green hornblende, which, in any case, constitutes a rim around them. *Amphibole* is always associated or intergrown with augite.

Well developed flakes of *biotite* are present in large quantities.

Quartz individuals are interstitionally disposed.

54 PZ-5. – Fine-grained amphibole-biotite gneiss; *right side of the Indus river, about 500 m (1.700 ft) the south of Tungas, along the caravan-trail.*

The fine-grained rock is formed with very thin, subparallel and irregular bands, the colour of which is either dark, or black, dark-grey, light-grey or locally light because of the large quantities of feldspar; the dark colours are undoubtly prevailing on the light ones.

Under the microscope one can see that the rock is constituted of a rather uniform aggregate of plagioclase, amphibole and biotite, the last being present in smaller quantities than the other components. Quartz is rare. The anorthite content of *plagioclase*, the individuals of which are perfectly clean and well twinned, is 35-40%.

Hornblende and *biotite* show anoriented disposition, altough not a rigorous one.

To this commoner kind of bands, other bands alternate, which differ from the first ones in a smaller quantity of mafic minerals (biotite being rare) and in the clearer crystalloblastic texture.

Lastly, in other bands, biotite prevails on amphibole and sometimes constitutes the only mafic mineral.

This rock does not differ too much from the fine-grained basic gneiss the author observed in the lower trunk of the valley and particularly in the area of Twar.

54 **PZ-6.** – Leucogranite with rare earth-epidote; *right side of the Indus valley to the north of Gurbidas, near Burum.*

The rock has the aspect of a light granite with a slight schistose texture, due to a certain orientation of the black mica.

The essential components are microcline, quartz, plagioclase and micas.

Microcline, sometimes enclosing coarse quartz grains and seldom biotite and muscovite, is almost often well twinned; *perthite* and *microcline-perthite* are present in some cases.

Coarse grains of *quartz* occur in smaller quantities than K-feldspar.

Plagioclase, corresponding to *oligoclase* (20-32% An), is present as xenoblastic individuals, which are seldom twinned; *antiperthite* associations are often seen.

Biotite and *muscovite* appear with crystalloblastic and rather well developed poikiloblastic flakes: their crystals are often intergrown.

Among the accessory minerals a great interest is given by a *rare earth-epidote*, its accentuated pleochroism varying from dark to dark-red tones. Its euhedral crystals are distributed with a certain uniformity in the rock.

Apatite is quite rare.

54 **PZ-7.** – Fine-grained biotite-amphibole gneiss; *right side of the Indus valley, to the north of Gurbidas, near Burum.* (Analysed rock).

This rock constitutes a basic portion enclosed in a granitic mass; the hand-specimen has the same aspect as 54 PZ-5, 6 samples, from which it differs only in the absence of the thin lighter bands.

The similarity of these rocks is corroborated under the microscope too, although, in this case, a finer grain, a more elongated habit of the *amphibole* crystals and a smaller amount of *biotite* can be noticed.

Quartz is almost lacking; the An content in the *plagioclase* individuals varies quickly and gradually from the more calcic inner zone to the outer zone, ranging from 37% An to 20% An.

54 **PZ-8.** – White marble; *right side of the Indus river, at Burum.*

The not very massive rock, is formed with large and quite white crystals of *calcite.*

54 **PZ-9.** – Fine-grained acicular amphibole-biotite gneiss; *right side of the Indus valley, a little to the south of Tungas.*

This rock, interbedded with two great limestones bands, resembles 54 PZ-5 and 54 PZ-7 samples, but is darker, less massive and lustreous for the presence of small acicular hornblende crystals. Analogous type-rocks can be observed many kilometres below, not far from the limestones outcropping near Mulakor.

The similarity of this rock with the above ones is confirmed also by microscopical investigation, in spite of the larger amount of *amphibole*, whose habit is quite acicular.

Plagioclase individuals composition is uniform.

Among the accessories *titanite* is common.

54 **PZ-10.** – Amphibole gneiss; *right side of the Indus valley a little to the south of Tungas.*

The dark and massive rock, with the same appearance as a hornfels, is interbedded, as 54 PZ-9 sample, with limestones.

Under the microscope it shows to be similar to 54 PZ-5, 7, 9 amphibolites, although, in this case, biotite is lacking or nearly lacking, titanite (sphene) being present in a rather large quantity. The An content of *plagioclase* crystals varies gradually from the more calcic core to the more sodic outer zone.

Epidote is generally found in small amounts, except in some light portions visible in the hand-specimen too, where it is present as large euhedral crystals being, together with *titanite*, the only mafic mineral of these parts. Here plagioclase grains show numerous inclusions, which may be interpreted as alteration products or, more likely, as alterating relics.

54 **PZ-11.** – Hyperstene diorite with large biotite flakes; *right side of the Indus valley, near Tungas.*

This rock, found close to the limestones layers, is similar, as 54 PZ-4 sample, to some monzonites. Its most strikingly character is due to the presence of some biotite unoriented patches, up to three-four centimetres across.

As it can be seen under the microscope, it approximates in many characters to the mafic type-rocks of Twar mass (54 PZ-21, 62, 63).

The more abundant component is a *labradorite-andesine plagioclase* (48-54% An), the grains of which are elongated and generally albite or albite-Carlsbad twinned; the composition planes, arranged in a subparallel disposition, give rise to a certain oriented structure.

Quartz is present only in small amounts, being interstitial among the euhedral plagioclase crystals; locally it may be more abundant.

The mafic minerals are pyroxene and biotite.

The usual *pyroxene*, regularly distributed in the rock, is of the pale-pink *orthorhombic type*, intergrown with *augite*; the « schiller structure » is hardly sensible.

Biotite is present with exceptionally well-developed flakes with sieve structure due to numerous pyroxene inclusions. A narrow border of *hornblende* is almost always visible between pyroxene and biotite.

This rock, compared with the hypersthene-diorites of Twar, displays the following peculiar characters:

1) Hornblende is always present in small amounts only as rims around some pyroxene crystals, showing to be, in this way, an alteration product. Its crystals are generally poikiloblastic.

2) The rock is crowded with acicular inclusions: acicular minerals are present in the plagioclase of the mafic diorites of Twar too, but are exceptionally numerous in the rock under investigation. The inclusions are always arranged in well definite directions, giving the appearance of sagenite aggregates.

3) K-feldspar is always lacking.

Lastly the greater amounts of *iron ores* can be noticed.

Para-postcrystalline deformations are quite common.

54 **PZ-12.** – Fine-grained amphibole-biotite gneiss; *right side of the Indus valley, near Tungas.*

The rock, taken about 50 metres to the north of the limestones layers, is grey with numerous dark lenticular patches, arranged according to the schistose surfaces.

Under the microscope it can be seen its similarity with 54 PZ-5, 7, 9, 10 samples, taken farther south, from which it differs only for the presence of bands or beds composed principally of *amphiboles.*

Locally *chlorite* and *epidote* may be found.

54 **PZ-13.** – Fine-grained biotite-amphibole gneiss; *right side of the Indus valley, 2 km to the north of Tungas.*

The quite dark rock, with rather lustreous schistose surfaces, is interbedded with coarser-grained mafic rocks.

Although similar, for many characters, to the dark schists taken further south, it shows, however, to contain much larger quantities of mafic minerals, among which *biotite* prevails.

54 **PZ-14.** – Banded amphibole gneiss; *at the junction of the Indus and Turmik valleys, between Baycha and Dasu.*

The hand-specimen shows light *feldspathic bands* alternating with dark *amphibolitic* or *amphibolic* ones. In field exposure the light gneissic bands look like injection dykes into amphibolic rocks.

Under the microscope it can be seen the transition from the amphibole beds to the lighter gneissic bands occurring in the following way: a *quartz-plagioclase* stripe (with albite-oligoclase more abundant than quartz) is found close to the amphibole bands, in which the only mafic mineral is *hornblende.* Going away from the amphibolic bands, *biotite* is seen, whose amount gradually increases up to the point to equal green hornblende. The arrangement of the even minute biotite flakes is parallel to the banding, that is to the schistose surfaces of the amphibolic rocks, in which these light gneisses alternate. Small *epidote* grains are found with hornblende and biotite.

Quartz and plagioclase are present in these bands as small isodiametric grains with well definite outlines, but some more developed patches of quartz can be found.

54 **PZ-15.** – Fine-grained quartz-feldspar gneiss with plagioclase porphyroblasts; *at the junction of the Indus and Turmik valleys, between Baycha and Dasu.*

The rock was found as concordant dyke into chlorite schists, the prevailing mineral being *chlorite* with $2V\gamma = 5^{\circ}$-6°. This fine-grained gneiss shows an aplite appearance with a slight schistosity due to the oriented disposition of the rare small micaceous flakes.

The peculiar structural motif, which can be observed under the microscope, is yelded by the presence of feldspathic porphyroblasts in a fine-grained, uniform, granoblastic matrix.

This ground-mass is formed with a minute aggregate of distinct grains of *quartz* and *plagioclase*, the composition of which ranges from 12% to 18% An. More developed, elongated crystals of *epidote*, *biotite* and larger *muscovite* flakes, arranged according to a definite direction, may be found in this matrix.

With patchy appearance, the feldspathic porphyroblasts, which consist sometimes of an only large *albite-oligoclase* (about 15% An) *poikiloblast* crowded with mica, epidote and, at the borders, quartz grains, are formed, other times, by the gathering of rather well-developed plagioclase crystallobasts with the above cited characters.

Finally it can be noticed a certain similarity between this rock and 54 PZ-16 dyke (page 195), found near the granitoide gneissic mass, outcroping between Skoyo and the Turmik valley.

53 **PD-2.** – Biotite gneiss with sillimanite and garnet; *right side of the Indus valley, close to Tsordas.*

The ash-grey rock shows a peculiar aspect due to the presence of some biotite flakes with no definite orientation, closely gathered in lenticular patches, besides the biotite crystals, uniformly distributed in the schistosity planes. In the section taken perpendicular to the plane of schistosity the rock looks, therefore, dotted with dark, rather regularly distributed patches. There is a great number of either concordant or discordant quartz veins.

Rocks of this type can be found on both sides of Shigar valley; to them 54 PZ-1 sample (page 201) can be related, its schistosity being yet less pronounced.

In thin section one can see the close similarity of the rock under investigation with 54 PZ-1 sample, to which the Author refers for a detailed description; it can be point out here that a very calcic *plagioclase* and *biotite* are the main minerals of this gneiss. The most remarkable differences with respect to the above mentioned sample are: 1) the almost complete absence of quartz grains (except for the portions close to the quartz veins), 2) the relative lack of sillimanite.

53 PD-3. – Biotite gneiss with labradorite poikiloblasts; *right side of the Indus valley, between Tsari and Tungas.*

The rock, showing a slight, irregular and schistose structure, is of a grey colour and dotted with frequent biotite patches and a few garnets; its aspect is rather uncommon: on one hand it could be related to the mafic 54 PZ-3 (pag. 203) gneisses, deriving from intrusive rocks metamorphism, on the other hand to the above mentioned 53 PD-2 biotite sillimanite gneiss. The rock is crossed by garnetiferous aplitic dykes.

The microscopical observation shows a quite peculiar mineralogical composition due to the association of *quartz*, *biotite* and minor quantities of *andesine-labradorite plagioclase*, whose well twinned grains exhibit sharp outlines; about fifty per cent of the rock consists of *labradorite poikiloblasts* (50-60% An) with the same size of the other minerals, always crowded of quartz grains, in addition to small quantities of biotite, apatite, iron ores and calcite.

Calcic plagioclase aggregates, like those of the 53 PD-2 biotite sillimanite gneiss, are locally seen, interstitially set among much larger individuals of other constituents.

Under the microscope the schistose structure is not clear, the texture being always a metamorphic one.

53 PD-4. – Hyperstene diorite; *right side of the Indus river, opposite Basha and Foldo.*

The composition of this rock is similar to that of mafic Twar type-rocks. It can be referred to 54 PZ-4 and 11 samples, taken near the place above cited; a coarser and more uniform grain can be observed in the rock under investigation.

53 PD-5. – Biotite gneissic micaschist; *right side of the Indus river, opposite Basha and Foldo.*

The rock displays a very dark colour; on the lustreous surfaces, due to the great amount of *biotite*, small twisted folds can be seen.

Here and there well developed *garnet* crystals are recognizable.

Quartz veinlets are frequent.

53 PD-6. – Biotite-amphibole gneiss; *right side of the Indus river, opposite Basha and Foldo.*

This massive, very dark and fine-grained rock is interbedded with the above mentioned 53 PD-5 biotite micaschists. Its mafic components show a slightly perceptible oriented disposition.

Under the microscope a clear schistosity is, instead, observed and the rock, on the whole, shows to be similar to the already described amphibolic types (54 PZ-9, 10 etc.); it can be pointed out in this case that the presence of some more developed *hornblende* individuals gives the rock a porphyroblastic appearance. These larger amphibole crystals are always crowded with minute iron and titane oxides inclusions, formed by segregation.

Rare *andesine* porphyroblasts have developed in the fine-grained ground-mass.

53 **PD-9.** - Leucogranite; *right side of the Indus river, opposite Foldo.*

The aspect of the rock is that of a granite with a quite light ground-mass, in which small *biotite* flakes are almost irregularly distributed. A quite peculiar character is due to the presence of frequent, slender biotite streaks and bands, which are quite elongated and almost always subparallel.

53 **PD-12.** - Fine-grained amphibole-biotite gneiss; *right side of the Indus river, near Tungas.*

The dark-greenish hand-specimen is similar to 54 PZ-9 sample (page 205).

53 **PD-13.** - Epidote amphibolite; *right side of the Indus river, a little below Tungas.*

The quite dark rock shows small black patches, formed by the gathering of mafic minerals and a grey ground-mass.

Under the microscope the rock appears constituted with *hornblende*, small quantities of *biotite* and *andesine* aggregates, which contain scarse amounts of *quartz*. *Epidote* is rather common.

53 **PD-14.** - Epidote amphibolite; *right side of the Indus river, between Tungas and Baycha.*

Well-developed black patches of mafic minerals can be seen in this rock, whose colour is quite dark.

Under the microscope green *hornblende* seems to be the prevailing mineral; *epidote*, *plagioclase* and *quartz* are in small quantities.

The texture can be defined porphyroblastic because of the remarkable sizes of some amphibole individuals.

53 **PD-15.** – Epidote aplite; *right side of the Indus river, near Baycha.*

The rock, dotted with numerous biotite flakes, shows a very fine grain.

Under the microscope it results constituted with a fine aggregate of a soda-rich *plagioclase* (*albite-oligoclase*) and *quartz*; K-feldspar is lacking. There is abundance of *biotite*, whose flakes are distributed with a certain orientation; *muscovite* is present in much smaller quantities, but with more developed flakes, with poikiloblastic character. *Epidote* is widely and uniformly spread.

THE ROCKS OF THE TURMIK VALLEY

54 PZ-83→91, 93→129; 53 PD-18, 18a, 19, 19a, 21, 21a, 21b, 22

54 **PZ-83.** – Calcariferous phyllitic sandstone; *left side of the Turmik valley, at a height of about 2600 m (8.500 ft) to the east of Smurdo.*

The rock, fine-grained and light-green coloured, shows a certain schistosity not perceptible under the microscope, although chlorite flakes are suboriented.

The rock is constituted with a very fine aggregate of *quartz*, *plagioclase*, *epidote* and *chlorite*. *Calcite* is less uniformly spread, being sometimes present as rather developed grains, or almost completely lacking.

The rock is crossed by calcite veins and generally the spots where these intersect are particularly rich in calcite. For this reason calcite may be regarded as a later product.

54 **PZ-84.** – Fine-grained amphibolite; *left side of the Turmik valley, in the scree, at a height of about 2800 m (9.000 ft) to the east of Smurdo.*

The rock shows a very dark grey colour and a quite fine grain.

It is constituted with *actinolite* needles, *epidote* aggregates and minute or quite minute *plagioclase* grains.

The schistose structure is quite evident.

54 **PZ-85.** – Fine-grained amphibole porphyrite; *left side of the Turmik valley, in the scree, at a height of about 2800 m (9.000 ft) to the east of Smurdo.*

The rock, similar to 54 PZ-84 sample, lacks any schistose structure; besides *actinolite*, *green hornblende* is present with a little more developed individuals.

54 **PZ-86.** – Schistose conglomerate; *near the bridge of Kushumal, in the scree.*

The sample shows to be constituted with elements of different kind and size; besides dark rounded elements, which correspond either to *serpentine* or to *fine-grained amphibolites* (as 54 PZ-84, 85 samples), little pinkish or dark-grey pebbles are present too, the nature of which the Author cannot define exactly; the light schistose cement is similar to that of the arenaceous phyllites, which autcrop near Kushumal, on the right side of the valley (54 PZ-87).

54 **PZ-87.** – Arenaceous blastomylonitic phyllite, with plagioclase porphyroblasts; *right side of the Turmik valley, to the south of Kushumal.*

The rock shows a lustreous-grey colour with irregular dark streaks due to an ununiform distribution of mafic minerals. On the weathered surfaces larger quartz and plagioclase crystals are in relief as knobs.

Under the microscope it can be seen a fine-grained part, which is constituted with granoblastic bands of *quartz* and *plagioclase*, alternating thin and irregular micaceous bands: these latter are formed with minute *muscovite* flakes, *sericite*, *chlorite* and small quantities of *epidote*; the coarse-grained portion of the rock consists of large individuals of *albite*, *quartz* and *calcite*.

The large *plagioclase crystals*, which are crowded with sericite, epidote microlites and, sometimes, calcite granules, are fractured and cemented with a minute aggregate of quartz and plagioclase.

The rock is cataclastically deformed, showing numerous lamination planes; all the major individuals look to be affected by strong cataclasis.

As the deformation was followed by almost complete recrystallisation, the rock can be defined blastomylonite.

54 **PZ-88.** – Diaphthoritic amphibolite; *right side of the Turmik valley, between Kushumal and Dasu.*

The greenish coloured rock can be defined as a partially diaphthoritic mylonite. Unaltered portions of *amphibole* can still be seen togheter with *chlorite*, the prevailing mineral.

54 **PZ-89.** – Saussurite melaphyre; *right side of the Turmik valley, between Kushumal and Dasu.*

In the hand-specimen a light ground-mass, dotted with greenish minerals, can be seen.

Under the microscope the rock shows to be constituted with *tremolite-actinolite* amphiboles, which are developed in a fine aggregate of zoisite. In much smaller quantities serpentine is present.

The original amphibole is evidently altering into an aggregate of amphibole needles and finally into antigorite.

Some ferriferous *epidote* grains are present too.

The rock is similar to 54 PZ-96 sample (page 215), which was taken in the wide deep valley to the west of Kushumal, close to the northern contact with the granitoide gneisses mass.

54 **PZ-90.** – Serpentine schist; *right side of the Turmik valley, between Kushumal and Dasu.*

The rock is very dark almost black coloured and massive.

It is constituted with either platy or more often fibrous *serpentine*, studded with numerous iron ores granules. Serpentine can be seen as pseudomorph after original minerals: at the core of each roughly poligonal patch of serpentine an aggregate of *talc* flakes, often with *calcite*, seldom with epidote, can be found. Talc flakes often trend as a network in serpentine, resembling irregular olivine fractures.

54 **PZ-91.** – Amphibole-epidote melaphyre; *right side of the Turmik valley, between Kushumal and Dasu.*

The main constituent of this middle-fine-grained rock is green hornblende which is present as prismatic-elongated crystals. *Plagioclase* is deeply altered into epidote or saussurite. *Biotite* flakes are almost always intergrown with amphibole.

Small *quartz* individuals are everywhere scattered.

54 **PZ-93.** – Epidote amphibolite; *in the wide deep valley to the west of Kushumal, near the contact with the granitoide gneisses mass, at a height of about 3200 m (10.500 ft).*

The aspect of this rock is that of a rather stretched amphibolite gneiss. Quite abundant dark lenses are delimited by thin, light beds, whose subparallel trend gives rise to the schistosity. Among these sialic bands amphibole is settled with either large or minute crystals, which often are gathered in aggregates.

Plagioclase, the only sialic component, is present as normally zoned crystals, whose An content is about 15% (the optic sign is now positive, then negative). In the plagioclasic aggregate *epidote* is distributed as numerous rather small grains.

Green hornblende, the dominant component, is present either as large crystals or as small prismatic elements, the latter being associated with *epidote*. On the surfaces of the larger individuals yellowish big grains of *rutile* are frequent.

54 **PZ-94.** – Epidote amphibolite; *in the wide deep valley to the west of Kushumal, at a height of about 3400 m (11.000 ft), near the contact with the granitoide gneisses mass.*

The rock has the aspect of an « augen gneiss » with ununiform composition; the « augen » are yellowish; it is quite peculiar the presence of thin, elongated, dark amphibolic lenses in a minute grey matrix of amphibole and plagioclase.

The schistosity is enhanced by the orientation of amphibole, which together with epidote is largely distributed in a plagioclasic ground-mass. Many epidote grains are gathered in patches elongated according to the schistosity, giving the rock the appearance of an « augen gneiss ».

Plagioclase is present as minute *albite* grains, among which small quantities of *quartz* can be found.

Hornblende, present as middle-sized individuals, shows a brilliant green colour.

Epidote is a slightly ferriferous type: the same composition can be found for the epidote grains associated with amphibole and for those of the larger patches.

54 **PZ-95.** – Epidote-actinolite schist with clinochlore; *in the wide deep valley to the west of Kushumal, at a height of about 3400 m (11.000 ft) near the contact with the granitoide gneisses mass.*

The light-green coloured rock is massive and fine-grained with a slight perceptible schistosity; dark green flakes dot the ground-mass.

As one can see under the microscope, amphibole, whose minute, elongated and prismatic crystals are faintly pleochroic in pale green tones, is the main constituent; this amphibole is intermediate in composition between *actinolite* and *hornblende*. With it *epidote* can be seen, the quantity of which locally becomes so abundant to equal that of amphibole.

Small *quartz* grains are interstitially found among these minerals.

On this minute matrix fine flakes of *clinochlore* (or prochlorite) are developed; these flakes, colourless to greenish, show grey interference colours, sharp cleavages according to (001) and a very small $2V\gamma$ (5^0-10^0); the average refractive index is close to 1,60.

As accessories dark grains of rutile are common.

54 **PZ-96.** – Epidote-tremolite porphyrite (?); *in the wide deep valley to the west of Kushumal, at a height of about 3500 metres (11.500 ft), near the contact with the granitoid gneisses mass.*

The rock has the aspect of a microtonalite for the presence of minute, greenish little elongated prisms, among which small light patches are found.

A clear schistosity is lacking.

The rock carries, as it can be observed under the microscope, rather well developed individuals of *amphibole* uniformly distributed in a ground-mass of small zoisite crystals.

Amphibole, being colourless or faintly coloured, with an extinction angle $c/\gamma = 15^0$-16^0, can be defined as a rather magnesium-rich member of tremolite-actinolite series.

The groundmass consists of elongated euhedral epidote (*zoisite* and *clinozoisite*) crystals, intricately crossing each other.

Small amounts of clinochlore are present.

54 **PZ-97.** – Acicular fine-grained amphibolite; *in the wide deep valley, to the west of Kushumal, at a height of about 3500 m (11.500 ft), near the contact with granitoid gneisses mass.*

The greenish coloured rock seems to be formed of thin sharply oriented needles.

Under the microscope it appears constituted with slender amphibole prisms, which are elongated and always arranged according to a definite direction. This amphibole is intermediate in composition between *green horneblende* and *actinolite*.

Rare epidote grains are attended by amphibole. *Rutile* grains are, instead, rather frequent. Small quantities of a *soda-rich plagioclase* (positive optic sign, low refractive indices) can be found in some quite thin beds, parallel to the schistosity.

54 **PZ-98.** – Amphibole gneiss; *in the wide deep valley to the west of Kushumal, at a height of about 3500 m (11.500 ft), near the contact with the granitoid gneisses mass.*

The strongly schistose rock is crossed by concordant and discordant fractures; its aspect is that of a fine-grained, rather laminated amphibole gneiss.

The similarity with this type of rock is confirmed under the microscope too; *green hornblende* is distributed with a certain order in a light plagioclasic-quartzose groundmass, the grain of which changes in irregular subparallel portions. Hornblende crystals are oriented, but never settled in beds or elongated streaks. Iron-titanium ores (magnetite, ilmenite, rutile) and rare epidote crystals are associated with amphibole.

Among the sialic components, *plagioclase* prevails by far over *quartz*. Na-Ca feldspar occurs usually in small individuals with extinction varying from the core to the outer zone; the composition can change in different individuals, as it is shown by the positive or negative optic sign; from the values of the refractive indices, always lower than ω of quartz, its average composition is to be regarded as about 15% An.

Quartz, which can be found as small grains in the finer-grained streaks, lacks almost wholly in the coarser-grained beds.

54 **PZ-99.** – Epidote amphibolite; *to the west of Kushumal, near the contact with the granitoid gneisses.*

The rock shows to be quite dark with uncertain, generally subparallel, light trains.

Amphibole crystals are minute, acicular and suboriented; the presence of *epidote* gives the rock a slightly yellowish-greenish colour.

54 **PZ-100.** – Fine-grained amphibolite; *to the west of Kushumal, near the contact with the granitoid gneisses.*

This rock consists mainly of *amphibole*, whose minute, acicular crystals give the hand-specimen a rather silky lustreous colour.

Rocks of this type occur also in the Twar zone, near the eastern or north-eastern contact with diorite-norite mass.

54 **PZ-101.** – Micaceous amphibolite; *to the west of Kushumal, at a height of about 3800 m (12.500 ft), near the contact with the granitoid gneisses.*

The rock, which doesn't show a definite schistose structure, is mainly formed with *amphibole* and *biotite*. Locally magnetite octahedra are found with a side of 0.5 cm.

54 **PZ-102.** – Epidote actinolite schist; *in the wide deep valley, to the west of Hurimul, at a height of about 4000 m (13.200 ft).*

This rock consists of *actinolite, epidote, clinozoisite* and small quantities of *plagioclase.*

54 **PZ-103.** – Conglomeratic paragneiss; *to the east of Kushumal, at a height of about 2800 m (9.000 ft).*

The rock showing light green colour and clear schistosity has lustreous surfaces due to the presence of minute mica flakes; small pebbles of different kind are uniformly distributed in the rock.

54 **PZ-104.** – Conglomeratic paragneiss; *to the east of Kushumal, at a height of about 2900 m (9.500 ft).*

The rock, similar to 54 PZ-103 sample, has more numerous and larger pebbles.

54 **PZ-105.** – Conglomeratic paragneiss; *to the east of Kushumal, at a height of about 3000 m (9.800 ft).*

Red, green, dark-grey pebbles are quite numerous and strongly strained according to the schistosity. Their largest size is about 2 cm.

54 **PZ-106.** – Conglomeratic paragneiss; *to the east of Kushumal, at a height of about 3000 m (9.800 ft).*

The rock is similar to 54 PZ-104 sample.

54 **PZ-107.** – Conglomeratic paragneiss; *between Kushumal and Hurimul, at a height of about 3000 m (9.800 ft).*

A few small pebbles are enclosed in a very fine-grained micaceous matrix.

54 **PZ-108.** – Schistose sandstone with calcite crystalloblasts; *left side of the Ganto-la valley, near the confluence with the Turmik valley.*

Carbonate crystals are developed in a fine-grained quartzose-feldspathic micaceous ground-mass.

The rock is similar to 54 PZ-112a sample; its schistosity is less evident.

54 **PZ-109.** – Phyllite with plagioclase and carbonate porphyroblasts; *left side of the Turmik valley, to the north of Hurimul, in the scree, near the bottom of the valley.*

The rock, fine-grained and grey or light-grey coloured, is dotted with dark minerals with noticeable development (about 1 cm); locally an almost perceptible schistosity may be seen.

The groundmass is formed with a fine-grained, indefinite aggregate of *plagioclase* and *quartz*, in which large quantities of *sericite* and *phengite* flakes are scattered. Porphyroblasts of a *soda-rich plagioclase*, considerable *carbonate* individuals and quartz patches occur in this matrix. The *quartz* patches are constituted by the gathering of rather large grains. *Apatite* is common too.

Carbonate porphyroblasts are filled with iron ores grains and rather commonly with small quartz individuals; rare are inclusions of plagioclase. At the borders of these porphyroblasts, associations of chlorite and sericite are sometimes found, with them apatite and quartz in some case can be seen.

Albite (or albite-oligoclase) *porphyroblasts*, crowded with great amounts of minute sericite-phengite flakes, never show definite outlines, being generally, for this reason, badly distinguished from the groundmass minerals.

Rarely plagioclase crystals enclose iron ores, which are, instead, settled around them, giving rise to a dark aureole. The same happens for the larger quartz grains, some quartz patches being, nevertheless, dotted with iron ores. Iron ores are present in the apatite crystals too.

54 PZ-110. – Arenaceous phyllite with carbonate porphyroblasts; *left side of the Turmik valley, at the mouth of Blanzgo Lungma.*

The fine-grained and light-green coloured rock shows a slight schistose structure, which is yielded by the oriented disposition of dark mica flakes; biotite crystals are rather well developed and distributed with a certain regularity.

In the groundmass yellowish or reddish apparently limonite crystals occur, whose habit is evidently rhombohedral. The matrix consists of *quartz* and *plagioclase* grains (the firts prevails), elongated according to the schistosity; *epidote* grains or prisms are present too; suboriented flakes of *muscovite* (or phengite) and *chlorite* are set in parallel trains. *Biotite* flakes display generally larger sizes, being mostly pleochroic in greenish tones.

Carbonate porphyroblasts, whose habit is clearly rhombohedral even with ragged outlines, show a sieve structure for the presence of numerous, more or less resorbed, quartz inclusions and seldom plagioclase and epidote grains.

During their development carbonate porphyroblasts thrusted aside the quartzose-micaceous bands of the groundmass.

54 **PZ-111.** – Arenaceous phyllite with carbonate porphyroblasts; *right side of the upper Turmik valley, near the mouth of Askobur Lungma.*

The rock, similar to 54 PZ-110 sample, was taken, like this, near limestones layers.

54 **PZ-112.** – Arenaceous epidote phyllite with carbonate porphyroblasts; *right side of the upper Turmik valley, near the mouth of Askobur Lungma.*

The rock, similar to 54 PZ-110 and 111 samples, differs from them only for the presence of large amounts of *epidote*: this minerals can be found in the groundmass, where it becomes an essential component of the rock. Carbonate porphyroblasts, which are smaller than in the above mentioned types, are present as unshaped patches with no sharp outlines.

As their inclusions quartz, plagioclase, micas, epidote, chlorite and iron ores can be found.

54 **PZ-112a.** – Phyllite with carbonate porphyroblasts; *right side of the upper Turmik valley, near the mouth of Askobur Lungma.*

The texture of the rock is sharply schistose, differing in this way from 54 PZ-110, 111, 112 samples, which are similar to this phyllite for many other characters.

Quartzose-micaceous beds (muscovite is present as small flakes) contain *iron ores*, *tourmaline* (schorlite) and larger *muscovite* and *chlorite* crystals; these beds are sinuous and twisted for the presence of quite numerous, unshaped and generally small porphyroblasts of *carbonate*, which show, for the rest, all the characters above described for the other similar rocks.

54 **PZ-113.** – Crystalline limestone; *at Askobur Lungma, 200 m (700 ft). above the junction with the Turmik valley.*

The rock, which is perfectly white, crystalline with even grain size, is crossed by frequent fractures.

54 **PZ-114.** – Amphibole gneiss with plagioclase porphyroblasts; *at Askobur Lungma, 150 m (500 ft). above the junction with the Turmik valley.*

The colour of the rock is a pale green, the schistose structure is clear: numerous, regular, elongated and depressed lenses are settled in the schistosity planes. In the section taken perpendicular to the lineation, plagioclase crystals can be seen.

The rock is formed, as it can be observed under the microscope, with an alternation of plagioclase bands with mainly amphibolic lenses. The bands, consisting of a fine-grained aggregate of a *soda-rich plagioclase*, contain also small quantities of *quartz*, *chlorite*, *epidote* and *amphibole*; in the more or less elongated amphibole lenses the grain is coarser and scanty *biotite* may sometimes be found.

In the fine-grained matrix *quartz lenses* or patches and feldspar patches or porphyroblasts are visible, the former constituted by the gathering of many quartz individuals of rather noticeable sizes; quartz is sometimes associated with a soda-rich plagioclase.

The *feldspar patches* are of so various a kind that it is quite difficult to describe or to define them clearly. They are sometimes constituted by the reunion of numerous large soda-rich plagioclase individuals, which are almost completely unshaped and crowded with small chlorite and epidote grains; they are separated by thin microgranular streaks of the groundmass, in which plagioclase grains are subordinate. Some other feldspar patches are matrix portions, where small quantities of quartz, chlorite and epidote are associated with plagioclase grains, each one of which shows an optic orientation slightly different from that of the surrounding individuals.

In these patches it can sometimes be observed that the optic orientation of a certain number of adjacent crystals is nearly equal in such a way to give to the patch the appearance of an indistinct porphyroblast.

The larger porphyroblasts, crowded with groundmass minerals, consist of portions of different orientation too, being, however, much more homogeneous.

54 **PZ-115**. – Epidosite with actinolite porphyroblasts; *at Blanzgo Lungma, a little above the junction with the Turmik valley.*

The rock is similar to 54 PZ-110, 111, 112 samples for its aspect, despite the lacking of large carbonate crystals.

Under the microscope the ground-mass shows to be formed with large quantities of *epidote* grains, which are associated with changeable amounts of *light mica* and *actinolite* needles; *plagioclase* is, instead, rather scanty and settled in little patches; *quartz* is present in small amounts.

Large actinolite crystals (some mm on side) have grown up in this matrix.

Numerous iron ores are distributed in the ground-mass or enclosed in the large actinolite individuals. Rare green tourmaline is present too.

54 **PZ-116.** – Crystalline limestone; *at Blanzgo Lungma, at the entrance of the canyon.*

This is a light marble, with greyish tones, which shows a middle irregular grain.

54 **PZ-117.** – Dark limestone; *at Blanzgo Lungma, in the canyon.*

This limestone is very dark-grey coloured, fine-grained and slightly argillaceous.

54 **PZ-118.** – Grey argillaceous limestone with calcite veins; *at Blanzgo Lungma, at the entrance of the canyon.*

This grey argillaceous limestone is crossed by a network of white veins of calcite.

54 **PZ-119.** – Grey crystalline limestone; *at Blanzgo Lungma, to the east of the canyon.*

The rock is clearly laminated.

54 **PZ-120.** – Schistose calcareous conglomerate; *at Blanzgo Lungma, to the east of the canyon.*

The rock consists of white, sometimes lentil-shaped marble elements, changing in size from 2 to 10 cm, which are elongated in a definite direction.

The quite scarse cement, which surrounds and coats the fragments, is formed with yellow-brown, perhaps epidote-rich material.

54 **PZ-121.** – Epidosite; *at Blanzgo Lungma, to the east of the canyon.*

The rock, quite similar to 54 PZ-115 sample, is greenish coloured with a slight schistosity. As 54 PZ-115 sample, it is likely to be constituted with prevailing epidote; in the hand-specimen, however, no porphyroblasts can be seen.

54 **PZ-122.** – Epidote-chlorite phyllite; *at Blanzgo Lungma, to the east of the canyon.*

The hand-specimen of this rock, pale green and schistose with darker thin lenses, shows to be similar to 54 PZ-110, 111, 112 and 126 samples. The essential components are likely to be chlorite and epidote, beside plagioclase and quartz.

54 **PZ-123.** – Epidote schist with biotite; *at Blanzgo Lungma, to the east of the limestones.*

The rock has a rather intense greenish ground-mass, with numerous biotite flakes.

Similar to 54 PZ-110 sample, this rock should be likely to contain a larger quantity of epidote.

54 **PZ-124.** – Epidote schist with biotite; *at Blanzgo Lungma, to the east of the limestones.*

The rock, which consists mainly of *sericite*, *feldspar*, *quartz* and *epidote*, is dotted with isolated *biotite* flakes, more developed than the other minerals.

54 **PZ-125.** – Amphibolite; *at Blanzgo Lungma, to the east of the limestones.*

The rock shows a schistose structure, enhanced by the presence of subparallel epidote-feldspar beds. Stout amphibole individuals are often noticeably developed.

54 **PZ-126.** – Chlorite schist with calcite; *at Blanzgo Lungma, to the east of the limestones.*

The colour of this rock is, on the whole, light greenish, changing however in patches or lenses. The main constituent is *chlorite*, whose colourless flakes with positive elongation show a felted arrangement and are sometimes gathered in patches unlike one from the other for the sizes of their individuals.

Iron ores are scattered in all the chloritic groundmass.

Carbonates are abundant and irregularly distributed as shapeless individuals, more often as patches formed by the reunion of big grains.

Serpentine is present too.

54 **PZ-127.** – Streaked crystalline limestone; *at Blanzgo Lungma, to the east of the limestones.*

These limestones are interbedded with the above mentioned 54 PZ-120, 126 rocks. Their peculiar character is the presence of irregular, light, subparallel, clearly cristalline bands, alternating with quite dark beds, whose grain is much finer.

54 **PZ-128.** – Epidote-amphibole-biotite schist; *near Matuntoro Klas, to the east of Ganto-la, in the scree.*

This rock, which can be found on the side of the Basha valley, is described here, with samples taken in the basin of the Turmik valley, because of its correspondence with the schists enclosed between the two great calcareous layers, largely outcroping in the Turmik valley. This rock is in fact stratigrafically equivalent to the types found at Blanzgo Lungma, to the east of the canyon cut in the limestones.

The schist in question shows a dark-grey groundmass, in which amphibole porphyroblasts can be seen.

The matrix consists, as one can see under the microscope, of suboriented *biotite* flakes, minut *epidote*, *amphibole* and rather small quantities of quartz and plagioclase.

Numerous, irregularly distributed patches are formed with associations of mafic minerals, whose sizes are much larger: generally *hornblende* dominates, being intergrown with changeable quantities of *biotite*, but aggregates of biotite with no orientation, which contain amphibole and seldom *epidote*, can be seen. In some patches with the above cited minerals large grains of *quartz*, *calcite* and sometimes a *soda-rich plagioclase* can be found.

Many veins filled with the already mentioned minerals, cross the rock in all directions.

54 **PZ-129.** – Feldspathic-quartzose gneiss with biotite and calcite; *near Matuntoro Klas, to the east of Ganto-la, in the scree.*

The schistosity of the rock, which shows a light, whithish matrix, is enhanced by the presence of slender, dark streaks and by the sub-oriented disposition of some lenticular spots with limonitic aspect.

Under the microscope the groundmass results constituted with a fine or a quite fine-grained aggregate of quartz and a soda-rich plagioclase. More developed biotite, calcite and plagioclase crystals are set in the groundmass.

Biotite, sometimes altered into chlorite, is attended by fewer *muscovite* and settled in long streaks.

Chlorite flakes, the size of which can change, enclose iron ores partially altered into limonite.

Numerous large *plagioclase* crystals, whose composition is that of *albite-oligoclase*, show rather well defined outlines and no orientation according to the schistosity of the rock: elongated plagioclase grains, in fact, are often arranged transversely to the foliation; these large individuals are always crowded with minute, uniformly spread sericite flakes, differing in this from the small plagioclase grains of the ground-mass, whose composition is quite similar. Slight, postcristalline deformations are visible in some crystals.

Quartzose-feldspathic bands of the groundmass are only sometimes displaced by the growing of the plagioclase.

53 **PD-18.** - Arenaceous phyllite with calcite; *left side of the Turmik valley.*

The presence of minute mica flakes gives a silver-grey colour to this rock, whose surfaces sometimes show an almost microscopic folding.

The rock consists, as one can see under the microscope, of a granular *quartzose-feldspathic* (the latter is scarse) aggregate, in which *sericite* and *muscovite* flakes are present, either uniformly spread or associated in elongated and folded streaks; calcite has a very irregular distribution, being rare in some portions and as abundant as quartz in others.

Iron ores are so numerous to constitute essential components.

As accessories abundant *tourmaline* and scarse apatite can be found.

53 **PD-18a.** - Epidote gneiss with plagioclase porphyroblasts; *left side of the Turmik valley.*

The rock shows a peculiar, locally intense, pinkish colour and numerous small cavities partially filled with brown material.

Despite the colour, the rock is quite similar to 54 PZ-110, 112, 114 etc. samples, in which the above cited cavities are generally filled with carbonates; these rocks are always found near the calcareous layers.

Under the microscope the rock results constituted with a fine-grained portion of quartz, plagioclase and epidote, in which plagioclase porphyroblasts can be found.

In the fine-grained portion small *albite* crystals are associated in patches with pinkish *manganesiferous epidote* (thulite) prisms, scarse muscovite and iron ores. Other patches are formed by the reunion of large *quartz* grains.

Pink epidote is locally so abundant to be prevailing on the other minerals, giving to the whole, with its roughly oriented arrangement a certain schistose structure.

Plagioclase porphyroblasts composition is that of *albite-oligoclase*: the An content is about 15%, being the refractive indices lower than ω of quartz and the optic sign generally positive but sometimes negative. Plagioclase porphyroblasts are unshaped and peculiarly studded with muscovite, quartz and epi-

dote: this last is sometimes pinkish and with the same composition of the one found in the fine-grained portions.
Epidote grains, thrusted aside during the growing of the porphyroblasts, quite often appear crowded around them.

53 **PD-19.** – Epidote-garnet amphibolite; *upper Turmik valley, under Stak-la.*

This fine-grained rock shows darker and lighter streaks alternating each other according to a different distribution of sialic and mafic minerals. Garnet is abundant.

The rock consists of isodiametric *plagioclase* (30% An) grains, attended by *green hornblende*, *clinozoisite*, *garnet* and much fewer quantities of *quartz*; the well developed, often poikiloblastic crystals of amphibole are sometimes associated with clinozoisite, which is present as isolated individuals too. *Garnet* crystals are always idioblastic.

The rock is similar to some mafic types found on the right side of the Askore valley.

53 **PD-19a.** – Amphibole gneiss; *upper Turmik valley, under Stak-la.*

Light and dark-green bands alternate in the rock; amphibole crystals set in subparallel planes, show a felted arrangement. Rocks of this type can be found in the lower part of the Turmik valley not far from the outcrops of granitoide gneisses with plagioclase porphyroblasts.

53 **PD-21.** – Quartz-feldspar gneiss with epidote and biotite; *under Ganto-la, towards the Basha valley.*

This is a light, schistose, quite strained rock, which shows to be dotted with biotite flakes. Dark mica individuals are either isolated or gathered in small patches, set in the schistosity planes, giving to the rock a similar appearance to that of 54 PZ-129 sample, found nearly.

Under the microscope an « augen » structure can be observed; thin prevailing *quartzose bands* with fine-grain, alternate rather coarser-grained bands, whose main component is *feldspar*; feldspar and quartz are attended by changeable quantities of *biotite* and *epidote*. The bands diverge, wraping about numerous roundish or lenticular patches, formed with aggregates of large, irregular individuals of *epidote* or and *plagioclase* (25-30% An), the latter always enclosing big crystals of the former; these two minerals seem, indeed, to be constantly associated with each other in different ratios.

With high magnifications the plagioclase patches appear formed of small unshaped individuals with no sharp outlines, which are separated one from the other by a minute quartzose-plagioclasic aggregate; in this aggregate adjacent feldspar granules show not very different optic orientation. A few, well twinned plagioclase crystals consist, instead, of an only large individual studded with epidote and quartz.

53 **PD-21a.** - Epidote amphibolite; *under Ganto-la, towards the Basha valley.*

The rock shows a light-green groundmass and a porphyroblastic structure due to the presence of large amphibole crystals; despite of the lighter colour, it resembles 54 PZ-128 sample, found close to this locality.

The rock carries, as one can see under the microscope, large green *hornblende* individuals, which give rise, at the borders, to *actinolite* needles.

The groundmass shows peculiar characters, being constituted with numerous *plagioclase* (10-12% An) individuals, with no sharp outlines, variously joined one to the other; among these grains abundant *epidote*, actinolite needles, biotite and titanite can be found; with plagioclase quartz grains are associated, which are gathered in distinct patches.

53 **PD-21b.** - Epidote amphibolite; *under Ganto-la, towards the Basha valley.*

The rock, rather coarse-grained, is a quite mafic type. Among amphibole crystals light green material, whose main constituent seems to be *epidote*, is interposed.

53 **PD-22.** - Dark streaked limestone; *under Ganto-la, towards the Baska valley.*

The hand-specimen shows light, hardly crystalline bands or lenses and dark-grey larger beds. The rock looks quite similar to some type-rocks, found in the left side of the Turmik valley, which alternate the large light limestones layers.

THE ROCKS OF THE SHIGAR VALLEY

THE ROCKS OF THE RIGHT SIDE

54 PZ-130→135, 264→284

54 **PZ-130.** – Tonalite; *right side of the Basha valley, in the wide deep valley to the west of Tisar, in the scree.* (Analysed rock).

The rock, middle-grained, differs from the normal tonalites in lacking of euhedral mafic minerals, which are sometimes gathered in patches.

The rock is chiefly made up, taking the minerals in order of abundance, of plagioclase, amphibole and quartz; the greater part of plagioclase crystals is peculiarly euhedral, quartz being instead interstitial. Subhedral or almost anhedral are the mafic minerals.

Plagioclase, whose composition is that of oligoclase-andesine 25-32% An, has a rim of *albite-oligoclasex* with 14-15% An ($n\gamma \simeq \omega$ of quartz; positive optic sign; maximum extinction angle in the symmetrical zone of albite twins = about 5°), besides being euhedral, is always well twinned and partially altered into sericite and epidote. The outer zones of the crystals only are generally fresh. Some plagioclase individuals enclose, besides epidote and sericite, chlorite and greenish biotite too; these minerals are likely to be filling products of fractures, subsequently recrystallized.

Plagioclase occurs sometimes only as patches enclosing fragments of the other components; these patches, which show generally peculiar spots indicative of changeable composition, are sometimes irregularly twinned, forming a chess-board pattern; their origin is to be ascribed to a recrystallisation following a cataclastic process.

Quartz, as it was before said, occurs in the interspaces among other minerals.

Among the mafic constituents *green hornblende* predominates, which is partially altered into biotite, epidote or actinolite.

The origin of *biotite* is almost always metamorphic; it can be either associated with amphibole, from which the former is derived, or gathered, as poikiloblastic flakes, in patches sharply delimited with a dark border from the remainig part of the rock. Green biotite can usually be set, as aggregates of fine flakes, in the altered plagioclase crystals or in the late-crystallized ones.

Amphibole is attended by large individuals of *pistacite.*

Apatite is present as notable prisms.

54 **PZ-131.** – Diaphthoritic tonalite cataclasite; *right side of the Basha valley, in the scree of the wide deep valley to the west of Tisar.*

The rock is massive and greenish coloured; in the hand-specimen dark-green minerals and lighter-green ones can be seen.

Under the microscope, in spite of the deep alteration of all the components owing to cataclastic deformations, it is still possible to recognize the nature of the rock, which was originally a tonalite.

The present main constituents are epidote, sericite, chlorite together as minute elements, and major quartz granules. Plagioclase and amphibole are present too.

Small *epidote* grains and *sericite* are often pseudomorphs after original euhedral crystals of *plagioclase*, being sometimes set around plagioclase individuals with a still well preserved core, which enclose large crystals of epidote.

Chlorite (penninite) is usually filling fractures, as radiating aggregates.

Quartz is present either as middle-sized angular grains, or as fine aggregates intermingled with the other components.

Green hornblende occurs as fragments deeply altered into chlorite.

Titanite is common.

54 **PZ-132.** – Epidote-sericite mylonite with amphibole; *right side of the Basha valley, in the scree of the wide deep valley to the west of Tisar.*

The rock quite similar to 54 PZ-131 sample, shows, in the hand-specimen, a coarser grain due to the presence of rather larger dark green patches in a much lighter-greenish ground-mass.

The rock consists of a finer-grained *epidote-sericite aggregate*, enclosing numerous highly undulant, sometimes fractured *quartz* grains and dark patches made up of *chlorite* only or, more often, of fractured, deeply chloritized individuals of *green hornblende.* Some other chlorite is yielded by biotite alteration.

The fine aggregate of the groundmass is quite likely to be derived from the alteration of original plagioclase, as it is to be noted in some cases. As the above cited sample 54 PZ-131 this rock can be regarded as a diaphthoritic tonalite cataclasite.

Among the accessories large crystals of a brown epidote, titanite and apatite can be remembered.

54 **PZ-133.** – Epidote amphibole schist; *right side of the Basha valley, in the scree of the wide deep valley to the west of Tisar.*

The rock is fine-grained; large irregular crystals of amphibole can be found in an uneven green groundmass. It is interbedded with quartz veins enclosing amphibole.

54 **PZ-134.** – Calcareous schistose conglomerate; *right side of the Basha valley, in the scree of the wide deep valley to the west of Tisar.*

In the hand-specimen crystalline light calcareous elements are recognizable, which are coated and cemented by rather small quantities of a phyllitic chlorite-sericite matrix. The rock is similar to 54 PZ-120 sample, which was found in Blanzgo Lungma (Turmik valley), but even more schistose.

54 **PZ-135.** – Fine-grained calcareous sandstone; *right side of the Basha valley in the scree of the deep wide valley to the west of Tisar.*

The rock, which is ash-grey coloured and fine-grained, contains minute micas flakes. A portion of the rock is regarded as deriving from greenschists for the presence of some greenish, perhaps epidotic patches.

54 **PZ-264.** – Cataclastic tonalite; *right side of the Shigar valley, on the walls near the bottom of the valley, to the north of Kaiyu.*

The rock, crossed by fractures filled with epidote, is quite similar to 54 PZ-130 sample, its groundmass being yet a little more greenish.

The similarity of these two rocks risults quite clear under the microscope too, either for the texture or for the mineralogical composition, the cataclastic process being here stronger and quartz in smaller quantities.

In some portions of the rock grains of albite-oligoclase (8-10% An; positive optic sign; refractive indices $< \omega$ of quartz; maximum extinction angle in the symmetrical zone of albite twins $= 11^{\circ}$-12°) are dotted with rather small quantities of sericite and epidote; in other portions, affected by stronger cataclastic deformations, plagioclase is quite wholly destroyed, yielding a minute sericite-epidote aggregate. In this latter case the rock has the same appearance as 54 PZ-131, 132 samples.

Quartz is fractured and can form patches of many small interlocked individuals.

Green hornblende is quite always present as strained fractured individuals, altered into *chlorite* and large, sometimes brownish *epidote* crystals.

Original biotite yielded probably chlorite and epidote too.

54 **PZ-265.** – Fine-grained biotite-epidote amphibolite with plagioclase porphyroblasts; *right side of the Shigar valley, in the bed of the torrent near Kaiyu.*

The rock, in the hand-specimen, is quite dark with black elongated lenses and yellow-greenish, epidote-rich patches in a massive groundmass.

The lenses showing a parallel arrangement give to the rock a schistose appearance. Some regular, lighter, suboriented prisms can be seen too.

The rock is chiefly formed, as one can see under the microscope, with a quite fine-grained aggregate of *green hornblende* needles, *biotite*, *epidote*, *iron ores*, *quartz* and *plagioclase.* Micas and amphibole, with their orientation, mark the schistosity of the groundmass, in which the following elements can be found:

1) thin and elongated lenses formed with the reunion of rather well developed, zoned *amphibole* crystals (whose core is often colourless and the outer zones bluish-green coloured) with *biotite* and, sometimes, with *epidote.*

2) patches of large *epidote* individuals;

3) large crystals of albite-oligoclase *plagioclase* (positive optic sign; refractive indices $<\omega$ of quartz and close to n of balsam) filled with *biotite*, *epidote* and, seldom, *amphibole.*

The origin of these porphyroblasts can be regarded as later than the metamorphic phase, which gave rise to the schistosity: this is, in fact, often cut by the plagioclase (replacement), which, in other cases, thrusted aside the minute mafic aggregate (concretionary growth).

The mafic inclusions found in the plagioclase crystals never show any preferred orientation.

The porphyroblasts were affected by deformations and fractures, which are filled with biotite, epidote and quartz.

Locally beds and lenses are formed with the reunion of small interlocked quartz and plagioclase individuals, attended by notable quantities of *calcite.*

54 **PZ-266.** – Porphyroblastic plagioclase gneiss; *right side of the Shigar valley, in the bed of the torrent near Kaiyu.*

The aspect of the rock is that of a porphyritic granite with ununiform composition, the mafic minerals being present in changeable amounts.

Rounded, quite dark biotite patches are common; in them, as in all the rock, large plagioclase individuals can be seen.

The rock is mainly constituted with large *plagioclase* individuals, either isolated or gathered in patches, which have developed in a middle-grained groundmass of interlocked *quartz* crystalloblasts of *biotite*, subordinate *green hornblende* and *epidote*.

Because of the large amount of plagioclase porphyroblasts, the groundmass components are set in the interspaces. Since the mafic minerals are gathered in patches too, it can be pointed out that each crystalline species tends to separate from the others.

Plagioclase crystals, whose average composition is that of *oligoclase* ($n\gamma < \varepsilon$ of quartz; negative optic sign) are often rithmically zoned and tend to be euhedral yet with jagged outlines. The boundaries against the other minerals are always quite sharp. Plagioclase crystals are crowded with small epidote granules and some sericite flakes, the latter being sometimes oriented in the host.

Biotite, hornblende (which is often partially altered into epidote), and large epidote individuals can be found in smaller plagioclase crystals and in the rims of major grains; these inclusions are to be regarded as relics of minerals replaced by plagioclase. The outer zones of some plagioclase crystals crystallized later than the cataclastic deformations by which this rock is affected too.

54 PZ-267. – Fine-grained amphibolite with plagioclase porphyroblasts; *right side of the Shigar valley, in the bed of the torrent near Kaiyu.*

The rock, dark and fine-grained, is similar to an amphibole microgabbro, showing yet a quite faint schistose structure; in this dark groundmass large feldspathic crystals are scattered.

Under the microscope the rock results formed with large quantities of amphibole (the only constituent of some patches) and small plagioclase crystals, which are set in the interspaces of the former, grading one into the other and being always filled with epidote, biotite and hornblende. Here and there large plagioclase porphyroblasts occur, devoid of sharp outlines; the inner part of these crystals encloses small quantities of minute epidote, the outer zones being crowded, instead, with large crystals of it together with biotite and hornblende.

Amphibole, a green hoinblende, is intergrown with changeable amounts of biotite, which is almost lacking in the patches with no plagioclase, being plentiful where plagioclase is abundant.

Biotite is sometimes altered into *chlorite*; these two platy minerals are often attended by *epidote* and either large crystals or perfectly euhedrals prisms of *rutile*.

Plagioclase is albite-oligoclase ($n\gamma < \varepsilon$ of quartz; positive optic sign; maximum extinction angle in the symmetrical zone of albite twins = 7°); its origin due to metamorphic process occurs through a partial replacement of the enclosed minerals.

Quartz is present only, as small granules, in some patches of the rock.

54 **PZ-268.** – Epidote-plagioclase gneiss; *right side of the Shigar valley, in the bed of the torrent near Kaiyu.*

The aspect of the rock is that of a granite or a cataclastic leucogranite, because of the uniform distribution of the mafic minerals, which occur in small irregular patches.

The rock is chiefly made up with notable euhedral crystals of plagioclase, sometimes gathered in patches; quartz, epidote and biotite, which form the remaining part of the rock, are set in the interspaces among feldspar.

Plagioclase crystals, whose An content is ranging from 8 to 15% ($n\gamma < \varepsilon$ of quartz; positive optic sign; maximum extinction angle in the symmetrical zone of albite twins = 11°-12°) are always filled with *epidote* and *muscovite* set parallel to definite crystallographic directions of the host. Large ferriferous epidote grains occur seldom in plagioclase. Because of the strong sieve structure of the major muscovite flakes and, sometimes, of epidote, these inclusions are to be ascribed to a metamorphic process. It is to be noted the presence in a plagioclase crystals of a rather bleached, twinned amphibole; this occurrence is quite peculiar because of the small amount of this component in the rock.

Quartz is present in patches as large interlocked individuals.

The coloured minerals, *biotite*, *chlorite* (the latter being yielded by the former) and *epidote*, are gathered in patches, often arranged between plagioclase and quartz; titanite and actinolite are present generally too.

Locally only abundant amphibole can be seen as large individuals.

Cataclastic deformations followed by a certain recrystallisation are observed in this rock too.

54 **PZ-269.** – Mylonitic granitic gneiss; *right side of the Shigar valley, between Kaiyu and Yonskil* (Analysed rock).

The aspect of the rock is that of a granitic gneiss for the sub-oriented arrangement of the dark mica.

Large feldspathic porphyroblasts occur in the fine-grained quartzose groundmass.

The interlocked *quartz* grains are uniformly middle-sized.

The porphyroblasts, in which the recrystallisation has completely obliterated the fractures, are constituted either with a soda-rich *plagioclase* ($n\gamma < n$ of balsam; positive optic sign) or *K-feldspar*, usually microcline. These large individuals are often coated with a quite fine feldspathic or quartzose-feldspathic aggregate, which outlines the occurrence of strong movements among crystals of different kind. In these fine blastomylonitic portions are often involved *biotite*, *muscovite* and *epidote* too. *Calcite* is also common. Some patches actually consisting of more feldpathic individuals might be formed, before the cataclasis, with one only or few crystals, that is the original porphyroblasts or phenocrysts should be larger-sized than now.

Myrmekites are here and there present along the border between plagioclase and K-feldspar.

Plagioclase is enclosing, as a rule, a certain amount of *muscovite*, *epidote* and, seldom in the rims, *biotite*. K-feldspar is crowded with small *plagioclase* grains and *quartz*. Muscovite and epidote should be partially yielded by the alteration of plagioclase; the other inclusions, which are not to be ascribed to the blastic process, must be regarded as previous products, being present in the original granite.

54 **PZ-270.** – Epidote-amphibole microdiorite with biotite; *right side of the Shigar valley, near Chundupon.*

The rock looks like a microdiorite with uniform composition due to the presence of numerous, irregular, almost wholly amphibolic patches up to several centimetres or some decimetres across.

Some other patches with a more developed feldspar can be seen.

The rock consists of *plagioclase*, *green hornblende* and *epidote*, these two last minerals, in quite the same amounts, are intimatly associated each other and with biotite. *Plagioclase* is albite-oligoclase (about 10-15% An; $n\gamma < \omega$ of quartz; positive optic sign; maximum extinction angle in the symmetrical zone of albite twins = 8°-10°); its crystals are generally well twinned and tend to be euhedral; some unshaped patches of plagioclase can be seldom found. Plagioclase crystals are sometimes enclosing muscovite and epidote, rarely biotite and hornblende.

Small *quartz* grains occur in minor quantities.

A little *K-feldspar* can be found in some portions made up of a rather indistinct sialic aggregate.

Apatite and *titanite* are abundant as accessories.

54 PZ-271. – Biotite-andalusite spotted slate; *right side if the Shigar valley, to the north of Matulu.*

The rock, fine-grained and grey-coloured, shows a clear schistosity due to the oriented arrangement of quite numerous black lenticular biotitic spots.

Under the microscope the rock appears constituted with thin quartzose-muscovitic beds devoid of biotite, containing changeable quantities of light mica. *Muscovite* is present as ever small equidimensional flakes so oriented that the schistosity planes, enhanced by it, trend at small angle to the original sedimentary bedding.

Quartz and *plagioclase*, which are often not easily distinguished one from the other, because of the small sizes of their grains, are always abundant in approximatly equal amounts.

In this fine-grained matrix rounded lenses occur, elongated according to the schistosity; the lenses are made up of middle-sized *biotite* flakes, not always parallel to the elongation of the lenses. The dark mica is usually attended by iron ores. The peculiar appearance of the rock is just due to the presence of these lenses.

Numerous other patches are formed with a great number of small isooriented *andalusite* granules intermingled with as many small quartz individuals. With the increasing of andalusite amount, its granules are knitting, giving rise to a large individual with a strong sieve structure.

These porphyroblasts, with their growing, sometimes thrusted aside the muscovite beds.

Among the accessories *tourmaline* is common, as even small grains.

All the groundmass is studded with a black dust, which might be graphite. The rock is crossed by veins and lenses of quartz with coarser grain.

54 PZ-272. – Calciphyre; *left side of the Shigar valley, to the north of Matulu.*

The rock consists of greenish perhaps epidote-rich calciphyres, alternating reddish biotite-rich bands.

54 PZ-273. – Argillaceous schists alternating calcic silicates bands; *right side of the Shigar valley, to the north of Matulu.*

The rock is constituted with an alternation of reddish originally argillaceous bands, with greenish ones. The bands are only a few centimetres, or sometimes a few millimetres in width.

Under the microscope one can see a rather irregular alternation of chiefly *quartzose-biotitic* bands with others containing, together with dark mica, changeable quantities of calcic minerals as *hornblende*, *epidote* (mostly *clinozoisite*), *pyroxene* and *calcite* too. Some portions of the rock are made up of these calcic minerals with no biotite, quartz being always present. The biotite-rich bands are generally fine-grained, the calcic silicates-rich ones coarser-grained.

In the biotitic beds the mica flakes are always well oriented; biotite is sometimes attended by an only minerals, clinozoisite, which is sometimes in small quantities; more often poikiloblastic amphibole occurs too, whose composition is ranging from actinolite to green hornblende.

Amphibole crystals are set at random. Small tourmaline grains can also be found.

With an increasing of amphibole and epidote too, biotite dwindles and disappears, while epidote and pyroxene become the most prominent constituents.

In the pyroxene-rich portions *titanite* is common.

In some other cases the limit between biotite bands and calcic ones is sharp. It is to be noted the presence of lenses or streaks of the former in the latter and viceversa.

The rock can be regarded as the metamorphic product of alternating argillaceous-arenaceous or arenaceous-calcareous layers.

54 **PZ-274.** - Gabbrodiorite; *right side of the Shigar valley, between Matulu and Pendo.*

The rock is middle-fine-grained and dark coloured for the large quantities of amphibole; locally, feldspar becomes more abundant, giving rise to a diorite-like rock.

A sample of the latter type results mainly constituted with amphibole and minor amounts of feldspar and quartz.

Plagioclase, whose An content is about 35% ($n\gamma \simeq \varepsilon$ of quartz; maximum extinction angle in the symmetrical zone of albite twin = 18°), is often deeply altered into sericite and epidote, which are sometimes gathered in cloudy aggregates. The outer zones of the plagioclase crystals, which are fresh in some cases, are enclosing, besides epidote, biotite and hornblende.

Quartz is abundant, though in subordinate quantities compared with plagioclase.

Amphibole is the predominant constituent, its composition being that of a green-bluish hornblende. It is often associated with biotite.

The accessories include frequent apatite.

54 **PZ-275.** – Calciphyres alternated with chlorite-biotite-schists; *right side of the Shigar valley, between Matulu and Pendo.*

The rock, fine-grained and massive, shows an irregular alternation of dark-green to black bands with light-green ones. The thin subparallel bands are formed either of amphibole or biotite and chlorite. Because of the hap-hazard arrangement of the minerals, no schistosity can be seen.

Amphibole is a colourless or faintly-coloured member of the tremolite-actinolite series or a green type intermediate in composition between actinolite and green hornblende.

Biotite, faintly pleochroic either when associated with amphibole or not, can always be observed in an initial stage of formation from *chlorite.* This points out the different rate of metamorphic recrystallisation occurring in beds of unlike composition.

The rock is crossed by rare, thin, concordant veins of labradorite plagioclase.

54 **PZ-276.** – Microgabbrodiorite; *right side of the Shigar valley, between Matulu and Pendo.*

The rock is dark coloured, massive and fine-grained; in the hand-specimen plagioclase can not be seen.

The main component of this rock is *green hornblende*, attended by subordinate quantities of *biotite* and *plagioclase.* This last mineral, whose composition is that of andesine-oligoclase (35% An; refractive indices > n of balsam; maximum extinction angle in the symmetrical zone of albite twins = 17°-18°) is present as laths roughly set accoiding to a certain direction, to this one the composition planes are parallel too. Plagioclase individuals are sometimes enclosing, besides apatite, epidote and little sericite, some hornblende or biotite crystals, which, maintaining their shapes, show to be in equilibrium with the host mineral.

All the rock is studded with iron ores and crossed by epidote veins.

54 **PZ-277.** – Gabbrodiorite; *right side of the Shigar valley, in the alluvium of the torrent between Pendo and Bhundo.* (Analysed rock).

The peculiar aspect of this middle-grained rock is due to the fringed, irregular shape of the black patches, formed with the reunion of the mafic minerals.

The main constituents are plagioclase and amphibole; minor quantities of biotite and quartz are present. The ratios of mutual implication between amphibole and plagioclase, causing the irregular shape of the large amphibole crystals, can point out a simultaneous crystallisation of these two minerals.

Well-developed *amphibole* crystals, whose composition is that of green hornblende, are often filled with no oriented *biotite* flakes. Numerous euhedral plagioclase grains are enclosed or implicated with hornblende, giving it a poikilitic appearance.

Plagioclase, which is andesine (maximum extinction angle in the symmetrical zone of albite twins = 20°; measurements made on albite-Carlsbad twins gave values ranging from 40 to 45% An) tends to be euhedral and variously twinned, the core of the crystals being sometimes more calcic (55-70% An) and deeply reabsorbed.

Inclusions of biotite and amphibole are not frequent, these two minerals being, however, clearly reabsorded and replaced by plagioclase.

Quartz is scarse and ever interstitial.

Titanite and *apatite* are rather common.

54 **PZ-278.** – Gneissic leucogranite; *right side of the Shigar valley, in the alluvium of the torrent between Pendo and Bhundo* (Analysed rock).

The rock shows a rather irregular distribution of the micas, which are sometimes set in discontinuous trains.

The main constituents of the rock, whose texture resembles that of a pegmatite, are quartz, plagioclase and K-feldpsar.

Plagioclase, an albite-oligoclase with 10-15% An ($n\gamma < \omega$ of quartz; positive optic sign; maximum extinction angle in the symmetrical zone of albite twins = 8°-10°) is present as large, usually unshaped individuals, often associated to form wide patches; in these individuals *muscovite* poikiloblasts and sometimes *biotite* are enclosed, the latter being altered at the border into a colourless mica, whose optic characters are similar to those of muscovite. As inclusions *calcite* and rare *quartz* can be found.

K-feldspar, generally *microcline*, is abundant; between plagioclase and K-feldspar large *myrmekitic* rims occur. K-feldspar is crowded with small plagioclase individuals.

Wide patches are formed with large, interlocked grains of *quartz* which can enclose plagioclase and K-feldspar.

The other constituents of the rock, *biotite*, *muscovite* and subordinate *epidote*, which are generally set around the large sialic individuals, can be regarded as mainly grown in a solid environment.

54 **PZ-279.** – Arenaceous biotite schist, interbedded with wollastonite calciphyres; *right side of the Shigar valley, in the alluvium of the torrent between Pendo and Bhundo.*

The rock is reddish coloured for the presence of minute biotite flakes in a massive arenaceous matrix; irregular lenses and light nodules grade, through greenish portions into the dark material.

In the fine-grained groundmass made up of rather equal quantities of small *quartz* granules and *labradorite*, numerous reddish *biotite* flakes occur, which show a certain oriented disposition on the whole.

With this dark schistose arenaceous material, rather concordant, coarse-grained lenses are interbedded; these lenses are exclusively formed with calcic silicates: radiating aggregates of *wollastonite* ($2V_\alpha \simeq 30^\circ$; $c/n_\alpha = 32^\circ$; negative-positive elongation), *diopside* granules and a little *epidote.*

Calcite is present too.

The quartzose-plagioclasic aggregate and the enclosed biotite tend to be coarser and coarser-grained approaching to the transition between the argillaceous-arenaceous bands and the calcic-silicates ones; this transition is outlined by a sharp, thin, coarse-grained band of quartz, pyroxene and amphibole, the crystals of these two minerals showing a strong sieve structure. The band grades rapidly into the wollastonite-diopside aggregate.

The coarser grain of these portions might be due to the presence of CO_2, let free during the thermal metamorphism of the calcariferous parts.

54 **PZ-280.** – Feldspathized biotite schist; *right side of the Shigar valley, to the north of Nielle.*

The rock, reddish-coloured and schistose, shows an alternation of quite thin darker and lighter bands; some quartz lenses can be seen too.

The darker bands are finer-grained and formed with an aggregate of *quartz*, *labradorite* (50-55% An; maximum extinction angle in the symmetrical zone of albite twins = 25°-30°) and small, reddish biotite flakes, whose roughly parallel arrangement gives to the rock a clear schistosity. In these dark beds more developed *microcline* crystals occur, which sometimes display a poikiloblastic structure with small inclusions of biotite, quartz and plagioclase. Biotite inclusions are never affected by reabsorption or replacement, (as it can be observed, instead, where biotite is enclosed in plagioclase).

Microcline can become so abundant or predominant as to be the only sialic component of these bands; in this case biotite flakes are coarser too.

The lighter bands are chiefly made up of rather large *quartz* grains and subordinate quantities of plagioclase and biotite.

The limit between light and dark beds is sometimes sharp; in some other cases one band grades into the other through a microcline-rich portion, which contains rather small amounts of biotite.

Besides the above cited minerals, *muscovite* poikiloblasts, *titanite*, *garnet* and, as accessories, *tourmaline* and *apatite* can be found.

54 **PZ-281-282a.** – Endometamorphic diorite, at the contact with epidote-pyroxene calciphyres; *right side of the Shigar valley, in front of the Shigar village.*

The rock is dark, fine-grained with an irregular distribution of the light minerals; it encloses greenish epidote-rich patches, which contain spots and streaks either of quartz, or of calcite, amphibole, garnet set at random.

The diorite-like portion consists of andesine *plagioclase* and *amphibole*; the former is present as uniform grains (45-50% An; maximum extinction angle in the symmetrical zone of albite twins = 25°-26°), the latter as more developed, elongated, strongly poikiloblastic crystals, whose composition is that of bluish-green hornblende.

Close to the contact with the enclosed calciphyres amphibole is bleaching, being associated with major and major quantities of *epidote*, *titanite* and, sometimes, *calcite*. Where the diorite-like rock is penetrating into the calciphyres, *diopside* or diopside-hedembergite occurs.

All the above cited minerals with notable amounts of calcite are the constituents of the calciphyres; *epidote* and *pyroxene* are quite abundant, locally a calcic *garnet* can be found.

The presence of large patches of quartz is quite peculiar: this mineral can sometimes enclose actinolite, which can be yielded by the metasomatic replacement of hornblende.

54 **PZ-282.** – Granite dyke; *right side of the Shigar valley, in front of the Shigar village.*

The rock, rather fine-grained, shows a certain gneissic appearance for the presence of suboriented biotite trains.

The rock, which consists mainly of *quartz*, *albite* (10-15% An) and *microcline* was affected by a cataclastic process followed by recrystallisation. *Biotite* is often set, as minute flakes, in the original slip surfaces.

Locally plagioclase was partially replaced by microcline, which encloses also numerous rounded quartz granules. Between plagioclase and K-feldspar *myrmekites* occur, which are abundant in the blastic portions, with quartz grains and plagioclase fragments.

As accessories *muscovite*, *calcite*, *allanite* and *zircon* can be seen.

54 **PZ-283.** – Fine-grained biotite gneiss; *right side of the Shigar valley, in front of the Shigar village.*

The rock is dark to black coloured and fine-grained with a schistosity hardly perceptible in some places, more visible in others.

The rock carries changeable but almost equal quantities of *quartz*, soda-rich *plagioclase* and *K-feldspar* (usually microcline); oriented or suboriented *biotite* flakes are here and there gathered to form lenses or trains parallel to the schistosity.

The accessories include *apatite*, *epidote* and *calcite*.

Lenses or irregular beds rich in *calcite* can be found in this rock; in them *amphibole* (green hornblende or actinolite), *epidote* and rather large poikiloblastic *titanite* crystals occur, while biotite is lacking.

The transition between the biotite portions and the amphibole-epidote ones is fast but gradational.

54 **PZ-284.** – Biotite-labradorite paragneiss with garnet; *right side of the Shigar valley, near Trachil.*

The rock is schistose, showing an alternation of ash-grey beds, which contain subparallel biotite lenses, with very thin quartzose ones. These rocks are similar to those found in the left side of the Shigar valley (54 PZ-237, 239, 242, 243) and in the Indus valley (54 PZ-1; 53 PD-2).

Even if this rock can be regarded as a lower grade metamorphic product, its similarity with the above cited samples is confirmed under the microscope too.

The main components are *biotite*, *quartz* and *labradorite*, these two last minerals being associated as small granules. Middle-sized biotite flakes are set at random in lenses concordant with the schistosity of the rock, while other ones, quite fine, are scattered in the quartzose-plagioclasic aggregate.

Garnet is scarse.

Small *tourmaline* crystals and iron ores are frequent, the latter being sometimes arranged as long trains. *Zircon* is enclosed in the biotite.

In the light beds, alternating the biotitic ones, besides *quartz*, a little calcic plagioclase occurs, which is going to be replaced by a soda-richer plagioclase.

Some indistinct portions of labradorite, quartz and biotite are enclosed in large andesine individuals; these inclusions might be relics of an original quartz-biotite-labradorite aggregate, dwindling away.

THE ROCKS OF THE LEFT SIDE

54 PZ-230→263

54 **PZ-231.** – Amphibolite with titanite; *under Skoro-la, on the side of the Shigar valley, at a height of about 4600 m (15.000 ft).*

The rock, which appears fine-grained, acicular, dark and schistose is quite similar in the hand-specimen to some amphibolites found in the Indus valley (close to Gurbidas and Tungas), in the Askore valley and in the Twar zone.

This similarity is confirmed by microscopical investigation too: a perfect correspondence of this rock with 54 PZ-71 (page 181) sample, taken in the Twar area, is ascertained. The main component is *green hornblende*, which is present as small individuals, oriented according to subparallel planes and tightly gathered.

In much lower quantities *plagioclase* is found, whose composition is that of andesine (30-32% An, negative optic sign, $n\gamma'$ close to ω of quartz, maximum extinction angle in the symmetrical zone of albite twins = 14^{o}-15^{o}); it occupies the interspaces among the amphibole crystals.

Titanite granules are quite common and widespread in the rock, they are often attended by iron ores. Biotite is rare.

54 **PZ-230.** – Biotite-amphibole gneiss with plagioclase porphyroblasts; *under Skoro-la, on the side of the Shigar valley, at a height of about 4600 m (15.000 ft).*

The aspect of this rock, which grades in the field into massive types, is that of a diorite gneiss. These type-rocks can be found as large bands in the 54 PZ-231 amphibolites, crossed by dykes with pegmatitic aplitic appearance.

The rock carries well developed individuals of *green hornblende* with bluish-green tones, which is irregularly distributed, being sometimes gathered to form pluriindividuals patches. Hornblende is generally attented by subordinate amounts of *biotite.*

More than fifty percent of the rock is formed with sialic minerals.

The most peculiar petrographic motif is given by the presence of a certain number of plagioclase porphyroblasts set in a rather fine-grained quartzose-plagioclasic aggregate. This aggregate is by far made up of *andesine plagioclase*, whose An content is nearly 35-38% (positive and negative optic sign, $\varepsilon > n_\beta > \omega$ of quartz; maximum extinction angle in the symmetrical zone of albite twins = 16°-22°). Its crystals, which are often twinned, are attended by numerous quartz grains. The porphyroblasts, as unshaped patches with sinuous outlines, show to have the same composition of the ground-mass plagioclase.

Numerous *epidote* needles and granules are present in the sialic portions, being gathered generally in swarms set here and there; in any case epidote si abundant as inclusions in the porphyroblasts, which contain also small quantities of biotite.

54 **PZ-232.** – Biotite-quartz gneiss with albite porphyroblasts; *near Skoro-Katza, upper Skoro valley.*

The aspect of this rock is that of an arenaceous, quite strained biotite gneiss.

Under the microscope it is possible to abserve:

1) A quite fine-grained portion chiefly made up of small *albite* crystals and of smaller quantities of *quartz*. This aggregate is always attended by minute *muscovite* flakes, which locally can be so abundant to become the main constituent of this fine portion.

With the above cited sialic minerals more developed *biotite* flakes can be found too. These are tightly gathered to form small streaks, indipendent from the fine-grained aggregate.

Very scarce is the epidote.

2) A middle-grained uniform portion, which carries solely *quartz*.

3) A portion formed with large unshaped *plagioclase* porphyroblasts, whose composition is that of albite, (about 10% An; $n\gamma < \omega$ of quartz, positive optic sign; maximum extinction angle in the symmetrical zone of albite twins = 10°-13°). These crystals are crowded with *sericite* and, in much smaller quantities, with *epidote*, *biotite*, *quartz*, *albite* and *calcite*; the quartz grains found in the porphyroblasts show in some cases the same dimensions of the quartzose aggregate individuals. Seldom they are affected by cemented fractures.

All these different portions are distributed at hap-hazard.

The fine-grained portion is arranged in the quartzose aggregate in streaks, lenses or patches joined together; a subparallel trend of these minute bands can be seen, as it is outlined by the arrangement of the micaceous minerals, mainly biotite.

A relation between the porphyroblasts and the albite-micas aggregate is likely to be, since the former, which is often rimmed by the latter, grows up mainly into it. In a few cases only, large plagioclase crystals, isolated in the quartz middle-grained patches, tend to develop with good crystal boundaries, differing in this way from the uniform patches, which can be found into the minute albitic aggregate.

K-feldpar is wholly lacking.

54 **PZ-233.** – Feldspar-quartz sandstone; *at Skoro-Lungma, about 1 km below Skoro-Katza.*

Sandstones of this type, which can be defined as arenaceous quartzites, are grey-pinkish coloured and dotted with minute dark lenses of biotite; they are often crossed by cemented fractures.

Under the microscope the rock shows to be fine-grained; the main constituents are *quartz* and *albite*, the former slightly prevailing on the latter; small quantities of *calcite*, *biotite* and *muscovite* are uniformly distributed.

54 **PZ-234.** – Phyllitic slate; *at Skoro Lungma, about 2 km below Skoro Katza, at the bottom of the canyon.*

The rock, which is silver-grey, micaceous and strongly foliated, is similar to 54 PZ-235 sample, being however, more phyllitic, strained and lighter than this. It is interbedded with sandstones analogous to 54 PZ-233 sample.

54 **PZ-235.** – Phyllitic slate; *at Skoro Lungma, a little below the canyon.*

The rock, foliated and grey coloured was affected by a quite slow grade of metamorphism.

It consists, as we can see under the microscope, of quite fine *sericite* flakes, which are sometimes attended by individuals of *chlorite* and *quartz*; this latter can be found either as small granules set in the micaceous beds or as coarser elements, which form stretched, sometimes wide lenses. Small quantities of a soda-rich feldspar are present.

Iron ores and *rutile* are uniformly spread in the rock as well shaped crystals; as granules, these minerals can be found in thin swarms. Tourmaline is rare. In the fine-grained aggregate euhedral poikiloblastic crystals, with no cleavages can be found. These crystals show the following optic characters: inclined extinction, biaxial with rather small $2V_\gamma$ (40^o-50^o), maximum interference colours upper blue of second order, faint pleochroism in yellow or pinkish tones.

extinction angle measured in plates with low birefringence from the composition plane of the twinned individuals = 37°. This component is likely to be monazite.

54 **PZ-236.** – Phyllitic carbonaceous slate; *middle-lower trunk of Skoro Lungma.*

This rock is interbedded with the above cited 54 PZ-235 types, from which it differs in the darker colour.

The similarity of these two rocks is confirmed by the microscopical investigation too: the rock in question is formed with an alternation of light *micaceous beds* with dark *graphitic* ones. Small quantities of *quartz* are present in the micaceous aggregate as minute granules, while coarser individuals of this mineral constitute thin beds or small lenses.

Chlorite is common, as flakes more developed than micas; *calcite* is scarse.

54 **PZ-237.** – Andesine paragneiss with biotite and garnet porphyroblasts; *Shigar valley, between the junction of the Skoro and Bauma-Harel valley.*

The rock shows a lustreous ash-grey groundmass dotted with large biotite flakes and rare garnets. Despite the lacking of any oriented disposition of the biotite porphyroblasts, the different distribution of the dark mica in parallel bands gives the rock a schistose appearance.

The groundmass is formed with an alternation of thin middle-grained *quartzose lenses or beds* with larger bands, which consist of a quite fine plagioclasic aggregate. The An content of this *plagioclase* ranges from 40 to 45% An, being $n\beta \simeq \varepsilon$ of quartz and the maximum extinction angle in the symmetrical zone of albite twins = 24°. Plagioclase is attended by quartz and *muscovite*, whose equidimensional flakes are uniformly spread and well oriented in a definite plane. In some cases these three components are associated in the same amounts, but more often indefinite portions, elongated according to the schistosity, can be found, in which *andesine-muscovite* or *quartz-muscovite* prevail. Muscovite is sometimes attended by small *biotite* flakes.

In this matrix biotite and garnet porphyroblasts are developed. *Biotite*, which is more abundant, is present as large poikiloblastic flakes set usually in a crosswise direction according to the foliation; the more common inclusions, quartz and plagioclase, are arranged in streaks parallel to the schistosity; the same happens to some iron ores tablets enclosed in biotite, while others are set at random. *Tourmaline* inclusions do not show any oriented disposition.

A strong sieve structure occurs also to the faintly purple-pinkish *garnet*, whose quartzose inclusions, oriented and elongated according to the foliation, give it a peculiar appearance.

In small quantities *muscovite* can be found: its porphyroblasts are similar to that of biotite, but with a stronger sieve structure.

As accessories *andalusite*, *kyanite*, *staurolite*, *sillimanite*, *tourmaline* and *zircon* are present.

54 **PZ-238.** – Leucogranite; *left side of the Shigar valley, between the mouth of the Skoro and Bauma-harel valleys, in the scree.*

This rock, middle-coarse-grained, was taken in the scree under the walls; the author is not sure that granite of this type outcrops in the tract of the valley under investigation, since in this side some moraine patches can also be found, from which this sample should be derived.

The rock is made up of quartz, K-feldspar and plagioclase; in small quantities biotite is present too. The texture can be defined as xenomorphic-granular, since the smallest plagioclase grains only tend to be euhedral.

Quartz, which appears sometimes insinuated among the other minerals, constitutes large patches rarely enclosing small plagioclase grains.

K-feldspar encloses, as *microperthites* or *microcline-perthites*, quartz, biotite and small euhedral plagioclase crystals.

Plagioclase, whose composition is that of *albite*, encloses rare quartz, biotite and small plagioclase grains, which show to have the same composition of the host, but different orientation. Along the boundaries between plagioclase and K-feldspar *myrmekites* are localized. This does not happen around the small individuals of plagioclase enclosed in the microperthites, whose rim is pure albite.

Biotite and rare *muscovite* are generally set in the interspaces.

54 **PZ-239.** – Labradorite paragneiss with biotite and garnet porphyroblasts; *Shigar valley, between the mouth of the Skoro and Bauma-harel valleys.*

The rock, quite similar to 54 PZ-237 gneiss, differs from it in the darker colour of the matrix and in the smaller sizes of biotite.

By the microscopical investigation the quite uniform groundmass risults constituted with a fine-grained aggregate of *labradorite* or, at most, labradorite-bitownite 55-70% An ($n\alpha >> \varepsilon$ of quartz; positive optic sign), *quartz* and *muscovite* with oriented flakes; small quantities of *biotite* can be seen too. Rare streaks of quartz are present.

The major *biotite* individuals are never so developed as in 54 PZ-237 sample; they always show to be crystalloblastic and elongated according to the foliation planes, as to which, however, the mica cleavage planes are generally discordant.

Garnet, never euhedral, is elongated in the schistosity planes as stretched poikiloblasts.

As accessories *kyanite*, *tourmaline* and *zircon* are to be remembered.

54 **PZ-240.** – Biotite-amphibolite with garnet; *Shigar valley*, *between the mouth of the Skoro and Bauma-harel valleys.*

The rock is similar to 54 PZ-241 sample, from which it differs only in a peculiar richness of biotite, gathered in some patches, and in the presence of small amounts of sulfides. The rock contains also some spathic calcite.

54 **PZ-241.** – Biotite amphibolite with garnet; *Shigar valley*, *between the mouth of the Skoro and Bauma-harel valleys.*

This rock, as the above cited 54 PZ-240 sample, crosses discordantly the andesine or labradorite gneisses with biotite and garnet (54 PZ-237, 239); it is middle-fine-grained, and dark to blak coloured.

The main component is a *green hornblende* with light colours and a strong sieve structure. Its individuals, some of which only are oriented in a definite direction, are attended by subordinate quantities of poikiloblastic *biotite* crystals.

The interspaces between these minerals are occupied by a fine granoblastic aggregate of *quartz* and *labradorite.*

Large crystals of *iron ores* are quite common; rare is *garnet* as euhedral individuals.

54 **PZ-242.** – Labradorite paragneiss with biotite porphyroblasts; *at the mouth of the Bauma-harel valley.*

The rock is schistose with slender light and grey bands; in the latter rather well developed biotite flakes can be seen. On the whole the rock is quite similar to 54 PZ-237, 239, found a little farther to the north.

This similarity is confirmed by the microscopical investigation too. The rock is constituted with an alternation of quartzose bands with quite thin beds or larger lenses of quartz and plagioclase.

In the quartzose bands *quartz* is middle-grained and attended by small quantities of *calcite*, *biotite* and *muscovite*, micas being always as minute flakes.

The thin beds are made up of the usual fine-grained granoblastic aggregate of *labradorite* and *quartz*, the former prevailing generally over the latter; these two minerals are, instead, in the quite same amounts in some larger bands. Coarse *biotite* poikiloblasts, set transversely in the schistosity planes can be seen in the quartz-plagioclase beds, which are stippled with clinozoisite, iron ore, tourmaline and zircon. Much scarcer is the muscovite.

54 **PZ-243.** – Epidote-labradorite gneiss with hornblende and biotite porphyroblasts; *middle-lower trunk of the Bauma-harel valley.*

These type-rocks are interbedded with 54 PZ-242 paragneisses, to which they are quite similar in the hand-specimen; the main difference is given by the presence of amphibole among the phenoblasts. Some light lenses or streaks seem to correspond to calciphyres.

Under the microscope middle-grained quartz lenses or beds can be observed, which are attended by larger bands with biotite and amphibole porphyroblasts set in a quite fine-grained ground-mass of *labradorite*, *quartz*, *pistacite* and *clinozoisite*. The division among these bands is, however, not sharp, since in the *quartz* beds minute *epidote* granules and coarser *hornblende* crystals can be found; in the fine-grained bands, vice versa, small *quartz* patches with larger size are present.

It is to be outlined that *biotite* porphyroblasts are never so developed as in the similar rock-types with no amphibole. Moreover, one can remember the presence of some large bands, whose main component is *epidote*; in them *hornblende* only can be found as porphyroblasts. Some *titanite* is present.

54 **PZ-244.** – Actinolite-epidote green schist with large augite crystals; *middle-lower trunk of the Bauma-harel valley.*

On the greenish-coloured groundmass numerous well-developed black crystals can be seen; the rock is affected by slip surfaces and shows, in the field, a rather schistose structure.

The ground-mass is made up of a minute aggregate of *actinolite* needles and *epidote* granules, which are attended by *chlorite*; this mineral, however, can generally be found in the slip surfaces or in patches, which are likely to be pseudomorph after original mafic minerals.

In this fine matrix euhedral *augite* crystals, perfectly fresh, can be observed. The rock is likely to be the metamorphic product of an original basaltic tuff.

54 **PZ-245.** – Labradorite paragneiss with biotite and amphibole porphyroblasts; *middle-lower trunk of the Bauma-harel valley.*

The rock appears to be quite similar to the ones outcropping near the mouth of the valley (54 PZ-242, 243) being darker for the presence of noticeable quantities of amphibole.

The groundmass, made up of a fine *labradorite* aggregate, contains smaller amounts of *quartz* and *chlorite*, whose flakes are minute, isolated and oriented. The uniformity of this aggregate is interrupted by the presence of discontinuous thin beds of *quartz*, whose individuals show average size. *Hornblende* and *biotite* porphyroblasts are present too; the arrangement of biotite is always discordant according to the schistosity, which is enhanced, instead, by poikiloblastic hornblende crystals, pleochroic in green-bluish tones (n_α = light yellow, n_β = faint green, n_γ = bluish-green, $c/\gamma = 17^o$-18^o).

54 **PZ-246.** - Epidote-chlorite green schist; *middle Bauma-harel valley.*

The rock is schistose, green-coloured with light and dark patches. Under the microscope it appears affected by numerous slip surfaces, showing a flat lenticular structure due to the presence of *chloritic* lenses in an *epidote-chlorite* ground-mass. Microgranular *quartz* aggregates can be found here and there; small quantities of *sericite* and *calcite* are present too.

54 **PZ-247.** - Amphibole-pyroxene serpentine schist; *middle Bauma-harel valley.*

The rock is dark-grey to green coloured and shows numerous greenish lustreous surfaces of serpentine.

In a matrix of *serpentine*, *actinolite* and *chlorite*, *augite* and *hornblende* crystals occur, whose rims are fringed and irregularly altered.

Hornblende is zoned: the colour of the mineral changes from greenish to dark-brown in the same individual portions, which do not show any other variation of the optical characters. Despite the changing of colours, the composition of these parts is always that of a common hornblende.

Hornblende is deeply altered into fibrous actinolite or tremolite, while pyroxene is often partially altered into amphibole and serpentine as well.

54 **PZ-248.** - Conglomeratic green schist; *middle Bauma-harel valley.*

In this rock, evidently a conglomerate, a certain number of dark fragments with a liver colour are embedded in a slightly schistose matrix, greenish coloured and dotted with yellow-greenish patches.

The green matrix consists mainly of *calcite*, *epidote* and *chlorite*; the first mineral is the most abundant: its middle-sized grains, attended by small quantities of epidote, chlorite and feldspar seem to constitute the cement of some patches, chiefly made up of epidote. These patches, in which there are also chlorite, calcite, a little plagioclase and quartz, should be regarded as alteration products of original mafic minerals.

The original texture is still recognizable in the dark fragments, which represent portions of mafic effusive rocks deeply altered. Numerous small laths are wholly replaced by calcite. Major rounded patches of chlorite can be seen; iron ores, calcite and epidote constitute the groundmass.

54 **PZ-249.** – Quartz-feldspar paragneiss; *upper Bauma-harel valley, in the scree.*

The rock appears to be a reddish, fine-grained sandstone. Locally a phyllitic schistose texture can be seen.

The groundmass is constituted with a fine-grained aggregate of interlocked *quartz* individuals, which encloses small quantities of *chlorite* and is stippled with iron ores, especially *hematite*. In this matrix plagioclase can be found, whose composition is that of albite 6-8% An (low refractive indices; maximum extinction angle in the symmetrical zone of albite twins = 12°). Plagioclase individuals grade into the groundmass in a peculiar way, stretching out numerous elongated fibres into it (in the same way as what can be observed at the boundaries of some hornblende crystals, which are altering into fibrous actinolite).

These crystals of plagioclase are crowded with calcite and sericite.

Calcite is common too, its grains being middle-sized; large quartz crystals are rare.

54 **PZ-250.** – Greenish slate; *middle Bauma-harel valley.*

The rock consists of a close alternation of thin, irregular, argillaceous beds, more or less intensely greenish-coloured and quite fine-grained. The beds are constituted with the same materials, which form the different types of green schists associated with this rock (54 PZ-244, 246, 247, 248). In the hand-specimen some lenses of quartz are seen too.

54 **PZ-251.** – White marble; *Shigar valley, near the mouth of Skoro Lungma.*

The rock is a white, middle-grained marble.

54 **PZ-252.** – Labradorite-epidote paragneiss with biotite and muscovite porphyroblasts; *Shigar valley, near the mouth of Skoro Lungma.*

The rock, which is interbedded with marbles as 54 PZ-251, is dark-grey coloured, massive and rather banded; being locally dotted with biotite flakes, it resembles the labradorite gneisses with biotite and garnet, which outcrop a little farther to the south.

The rock is constituted with a fine quartz and plagioclase aggregate, in which large muscovite and biotite flakes are developing with clinozoisite crystals.

Plagioclase, whose composition is that of *labradorite*, prevails usually over *quartz*, with which it is always associated.

Biotite, whose flakes are poikiloblastic, reddish-coloured and discordant according to the schistosity, is a quite abundant component; generally the core of its crystals is rather well shaped, while the rims are so extremely poikiloblastic as to be formed with small isoriented micaceous portions, separated one from the other.

Some whole portions of the rock are sometimes stippled with isoriented flakes, which are scattered in the fine quartzose-plagioclasic aggregate.

Muscovite flakes, which are found in much smaller quantities, show a quite strong sieve structure too.

Clinozoisite is abundant, being present either as irregular dusty granules or as large crystals; this mineral is often enclosing rather well developed individuals or quite fine granules of calcite, these latter being set in parallel trains.

Clinozoisite is the dominant mineral of some patches (or bands), where it is associated with the ground-mass granoblasts: *chlorite*, *muscovite* and *calcite*. Biotite is absent. The origin of these patches is certainlv a later one, as the chloritization of the surrounding biotite shows.

54 PZ-253. – Granite; *Shigar valley, in the Daltumbore Lungma alluvium.*

The aspect of the rock is that of a fine-grained granite, which is provided with a faint schistosity due to a suborientation of many biotite flakes.

The main constituents are quartz, K-feldspar and plagioclase, a little biotite and muscovite being present too; as accessories epidote and titanite can be found. The micaceous flakes show a subparallel trend, locally better defined. Among the sialic components, plagioclase only tends to be euhedral.

Quartz is always seen as large elements with undulatory extinction.

Plagioclase, whose composition is that of oligoclase with about 20% An ($n\gamma \simeq \varepsilon$ of quartz, negative optic sign, maximum extinction angle in the symmetrical zone of albite twins = 0°-4°) is often crowded with quartz, muscovite and epidote (clinozoisite at most), seldom with biotite and a ceriferous epidote.

Plagioclase is often replaced by K-feldspar; the latter is often variously pervading the former, more or less notable portions of which are sometimes isolated by K-feldspar itself. Along the borders of these two mineral *myrmekites* occur.

K-feldspar (orthoclase, microcline, microperthite) is quite abundant and, besides plagioclase, quartz, biotite, muscovite and epidote can be enclosed in it.

Biotite and *muscovite* are often associated or intergrown.

Epidote (allanite too) is seen as clear crystals.

54 **PZ-254.** – Arenaceous quartzite; *Shigar valley in the Daltumbore Lungma alluvium.*

The rock is massive, quite fine-grained and light-grey to yellowish coloured. Here and there micas can be seen. This sample, despite of its deficiency of flaky minerals, is similar to an arenaceous quartzite found to the north of Skoro-la, in the side of Braldu valley.

54 **PZ-255.** – Pure quartzite; *Shigar valley, in the Daltumboro Lungma alluvium.*
The rock shows to be a white, laminated quartzite, containing locally minute sericite.

54 **PZ-256.** – Biotite-chlorite schist with actinolite porphyroblasts; *Shigar valley, in the Daltumbore Lungma alluvium.*

The rock shows a porphyroblastic texture due to the presence of large black amphibole crystals with no orientation in a fine-grained, schistose and light-green-coloured groundmass.

Under the microscope the fine-grained portion results constituted with a quite fine aggregate of *chlorite* and *biotite* lepidoblasts, set in parallel planes, which contain small quantities of *quartz*, *feldspar*, *epidote* and *titanite.*

In this aggregate large *actinolite* lenses can be found; actinolite, whose coarse and zoned crystals are obliquely or perpendicularly elongated according to the schistosity, is attended by *calcite* and small quantities of *chlorite* flakes, rather more developed than those of the groundmass. These lenses are often connected one to the other through thin and discontinuous beds particularly rich in calcite; they sometimes contain middle-sized amphibole and chlorite crystals.

Seldom average-sized individuals of actinolite are isolated in the groundmass.

54 **PZ-257.** – Arenaceous paraschist; *Shigar valley in the Daltumbore Lungma alluvium.*

The rock, which is schistose, grey-coloured and finely micaceous, might derive from the metamorphism of argillaceous-arenaceous materials.

54 **PZ-258.** – Muscovite micaschist with garnet and biotite porphyroblasts; *Shigar valley, in the alluvium of the wide deep valley between Daltumbore Lungma and Alchori.*

The rock has the aspect of a phyllitic micaschist with miniature folding and numerous large garnet crystals.

Under the microscope it shows corrugated schistose structure with sometimes twisted folds. *Muscovite* and *quartz*, whose individuals are middle-fine-sized, constitute the ground-mass; some beds are quite wholly micaceous, others, or better some patches, are instead, rich in quartz. *Graphite* is quite abundant in all the rock, especially in the micaceous beds, as quite fine granules, which give the rock a dark colour.

In this matrix large *garnet* crystals and middle-sized *biotite* flakes are developed; biotite, which is set in a crosswise direction according to the schistosity planes, is almost always crowded with very fine granules of graphite.

Some smaller *albite* poikiloblasts, which enclose, besides micaceous flakes, iron ores, quartz and graphite, can also be found in the groundmass, particularly in the muscovitic bands. It is to be noted that graphite trains pass unbroken from the micaceous bands through the plagioclase porphyroblasts.

54 **PZ-259.** – Tremolite calciphyre; *Shigar valley, in the alluvium of a gully between Alchori and Sildi.*

The rock is a very light marble, which contains large tremolite crystals constituted of the reunion of many parallel needles, sometimes diverging to form sheafs. Here and there minute micaceous flakes give rise to patches.

The rock carries, as it can be seen under the microscope, large *calcite* crystals and colourless amphibole (*tremolite*), this latter being set among the former either as large elongated individuals or, more often, as radiating aggregates of minute needles.

Biotite is scarce and rather magnesiferous as shown by the faint pleochroism; it is localized in patches and streaks, being sometimes intergrown with tremolite.

54 **PZ-260.** – Amphibolite; *Shigar valley, a little to the south of Sildi.*

The rock, schistose and middle-grained, is similar to some amphibolites of the Turmik and Indus valleys.

54 **PZ-261.** – Biotite augen gneiss; *Shigar valley, between Sildi and Yuno.*

The rock is chiefly made up of sialic minerals set in lenses elongated according to an only direction and separated one from the other by irregular subparallel beds of biotite.

Under the microscope the rock results formed with quartz, oligoclase, K-feldspar, biotite and muscovite.

Quartz is present as large individuals, being enclosed in feldspar as small rounded granules.

Plagioclase, whose composition is that of *oligoclase* with 20-25% An ($\varepsilon > \gamma > \omega$ of quartz; negative optic sign; maximum extinction angle in the symmetrical zone of albite twins = 3^o-5^o), is often intimately associated with small quantities of K-feldspar. Plagioclase is enclosing, besides quartz, large biotite flakes, muscovite, *epidote*, small *garnet* crystals and a little calcite.

K-feldspar (orthoclase), which is quite abundant, is sometimes enclosing all the above cited minerals; it reacts with plagioclase, to form myrmekite.

Biotite and *muscovite* are seldom associated, biotite only being oriented according to the faint schistosity.

The accessories of the rock include *tourmaline* and *apatite.*

54 **PZ-262.** – Fine-grained amphibolite; *Shigar valley, between Sildi and Yuno.*

The rock is quite similar to some amphibolites found in the Indus valley, in the Turmik valley and in the Twar zone.

54 **PZ-263.** – Amphibolite; *Shigar valley, close to Sildi.*

The rock is similar to some amphibolites, taken in the Indus valley, Turmik valley and in the Twar zone.

Padova, *Istituto di Mineralogia e Petrografia dell'Università.*

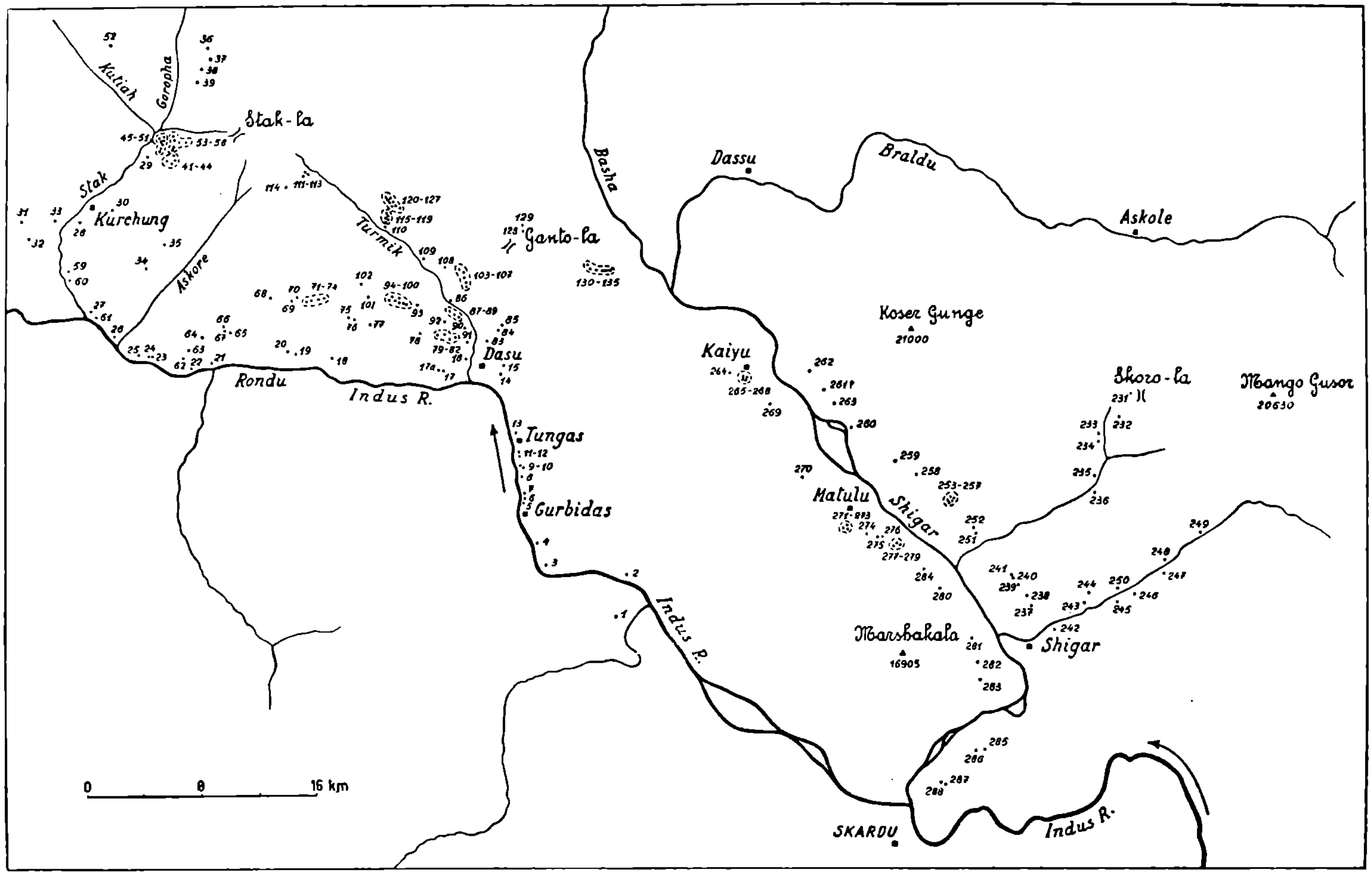

Fig. 11 - Localities of gathering of the samples. The numbers are the same reported in the text.

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PLATES

Plate 1

THE MIGMATITES OF THE STAK-HARAMOSH AREA

Fig. 1. - *Migmatitic augengneiss. - Left side of the lower part of the Stak valley* (54PZ-28). (About 1,5 nat. size).
In this rock the minerals of the neosome are rare and form isolated streaks or lenses, macroscopically visible. Under the microscope also thin bands of neosome may be recognized (see Plate 3, fig. 2).

» 2. - *Migmatitic augengneiss. - Near Kulankae* (54PZ-57). About 1,5 nat. size).
This gneiss has larger and more abundant " augen " than the rock shown in fig. 1. The neosome is also present as long bands.

» 3. - *Migmatitic banded gneiss. - Near Kulankae* (54PZ-43 a). (About 1,1 nat. size).
Some bands of paleosome fade away toward the neosome along the strike. Note that thin streaks of paleosome are always present in the neosome.

» 4. - *Migmatitic banded gneiss. - Lower part of the Stak valley, on the right side* (54PZ-32). (About 1,5 nat. size).
Typical migmatitic banded gneiss, with thin alternating of paleosome and neosome bands. In the light bands garnet porphyroblasts are clearly visible.

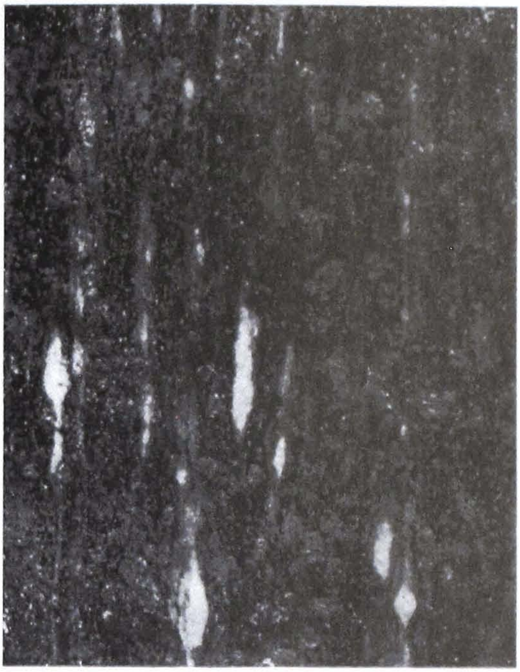

Fig. 1

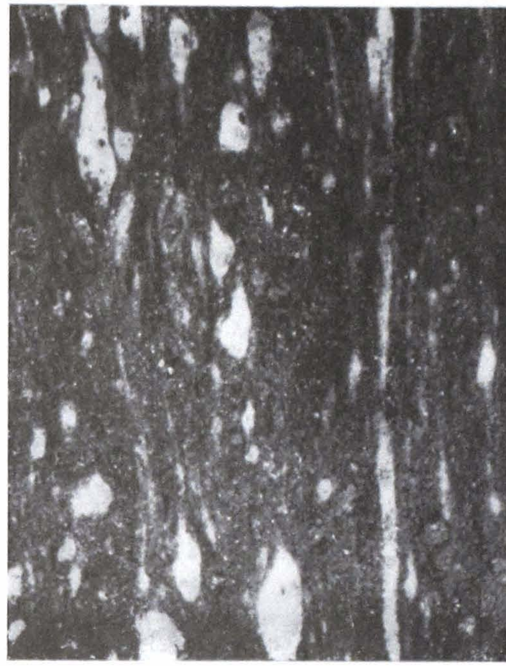

Fig. 2

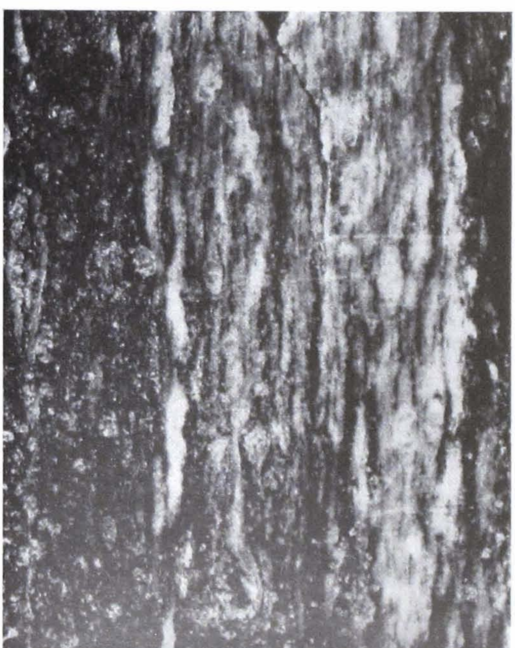

Fig. 3

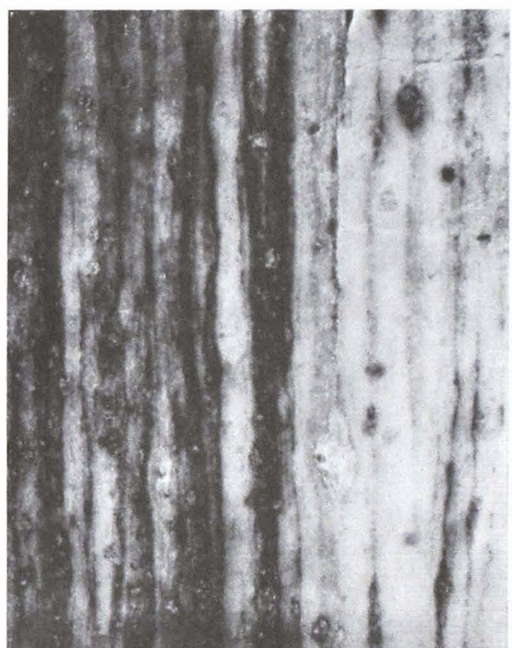

Fig. 4

Plate 2

THE MIGMATITES OF THE STAK-HARAMOSH AREA

Fig. 1. - *Migmatitic banded gneiss. - Middle part of the Stak valley, above the village of Kurchung* (54PZ-30). (About 1,5 nat. size).
The figure clearly shows the relations between paleosome and neosome. Inside the paleosome, the minerals formed by metasomatism constitute small irregular patches; inside the neosome thin streaks of paleosome persist.

» 2. - *Light (leucogranitic) band of a migmatitic banded gneiss. - Middle part of the Stark valley, above the village of Kurchung* (54PZ-29). (About 1,5 nat. size).
Where the light bands of this migmatitic gneiss are comparatively thick, the streaks of residual paleosome are especially abundant. Inside these bands one can distinguish purer portions, much lighter, enclosing only small quantities of paleosome.

» 3. - *Migmatitic pegmatitic gneiss rich in tourmaline, garnet and kyanite. - Left side of the Goropha valley* (54PZ-40). (About 1,1 nat. size).
Also in this rock the minerals, tourmaline included, show preferred orientation.

» 4. - *Migmatitic leucogranitic gneiss. - Left side the Kutiah glacier* (54PZ-52). (About 1,3 nat. size).
These rocks represent the most sialic migmatitic types; inside them the paleosome forms only rare, isolated bands. The kyanite is absent; garnet and biotite (the last, in course of alteration) are scarce.

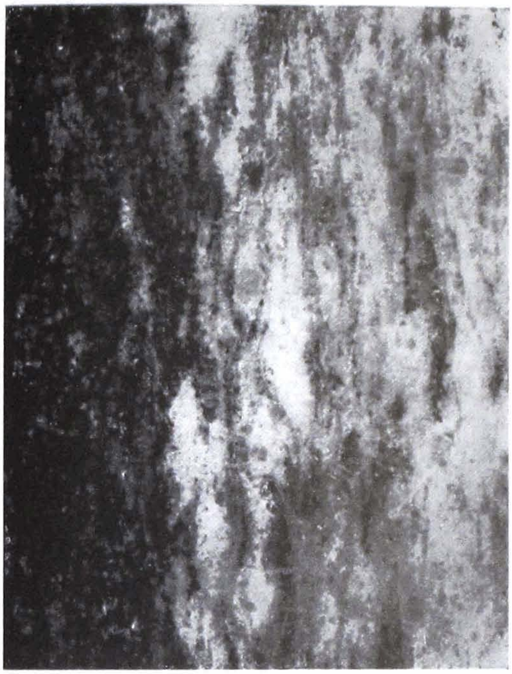

Fig. 1

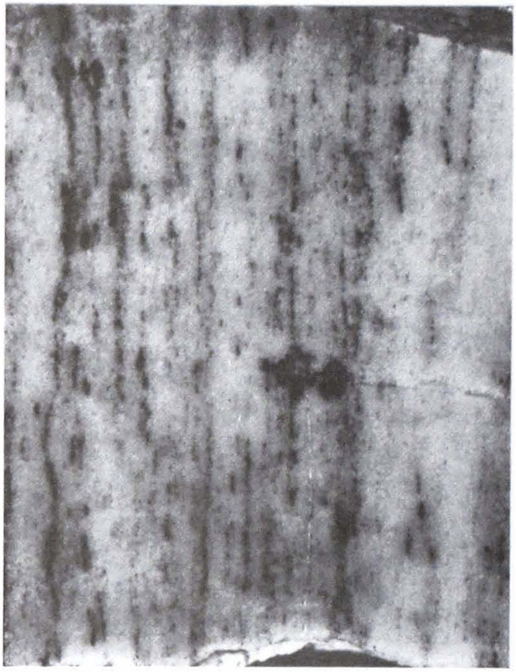

Fig. 2

Fig. 3

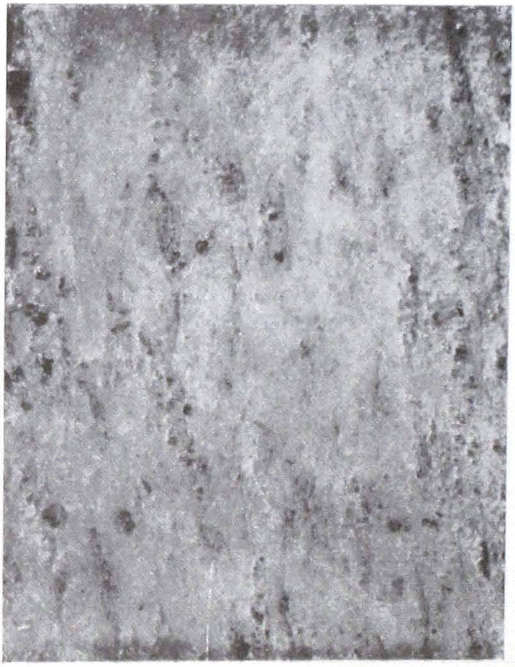

Fig. 4

Plate 3

THE MIGMATITES OF THE STAK-HARAMOSH AREA

Fig. 1. - *Migmatitic augengneiss. - Lower part of the Stak valley* (54PZ-28). (Plane polarized light; × 24).
Bands of paleosome, formed by the assemblage of biotite, muscovite, kyanite and garnet. The garnet is present with large porphyroblasts.

» 2. - *Migmatitic augengneiss. - Lower port of the Stak valley* (54PZ-28). (Plane polarized light; × 24).
Bands of neosome. With quartz and feldspars many crystals of kyanite are associated.

» 3. - *Migmatitic augengneiss. - Lower part of the Stak valley* (54PZ-28). (Crossed nicols; × 30).
Besides the layers formed by mica and kyanite and provided with quartz and feldspar granoblasts, in the paleosome are also present long and thin layers of quartz, formed by the union of large crystalloblasts lengthened according the schistosisty.

» 4. - *Migmatitic banded gneiss. - Middle part of the Stak valley* (54PZ-29). (Crossed nicols; × 30).
In the bands of neosome thin layers of quartz are alternated with layers formed by granoblasts of feldspars and quartz and by lesser quantities of mica and kyanite.

Fig. 1

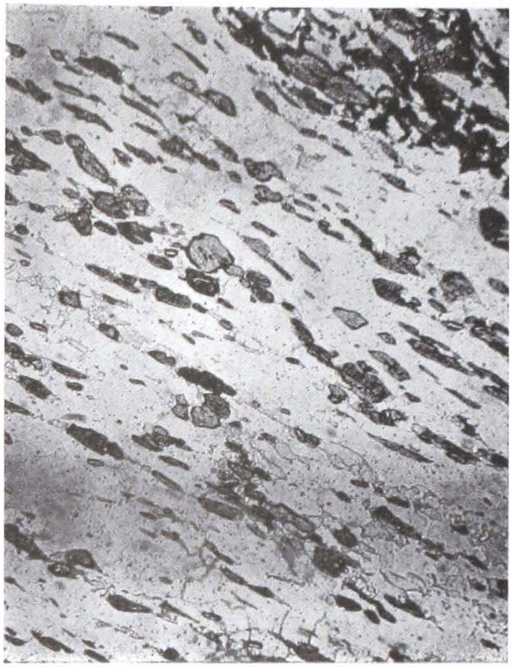

Fig. 2

Fig. 3

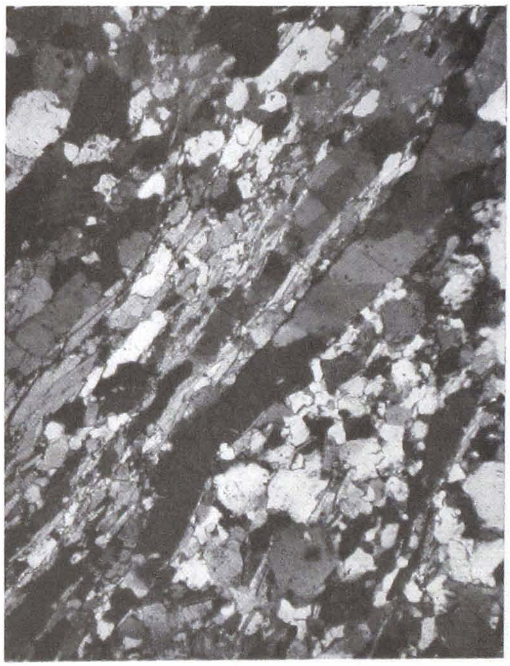

Fig. 4

PLATE 4

THE MIGMATITES OF THE STAK-HARAMOSH AREA

Fig. 1. - *Migmatitic banded gneiss. - Lower part of the Goropha valley* 54PZ-37). (Crossed nicols; × 28).
K-feldspar porphyroblast lacking in precise boundaries and enclosing granules of quartz.

» 2. - *Migmatitic banded gneiss. - Middle of the Stak valley* (54PZ-29). (Crossed nicols; × 80).
K-feldspar porphyroblast. It is to be remarked that this porphyroblast protrudes into the granoblasts of the matrix; it grows at the expense of K-feldspar granoblasts, (recognizable by the thin needles enclosed in them), and encloses the quartz granoblasts.

» 3. - *Migmatitic augengneiss. - Lower part of the Stak valley* (54PZ-28). (Plane polarized light; × 150).
Bent crystal of kyanite, intimately associated with biotite flakes.

» 4. - *Migmatitic pegmatitic gneiss. - Goropha glaciers* (54PZ-40). (Plane polarized light; × 36).
Kyanite converted to muscovite at the borders. At the lower left side of the figure one can see small needles of kyanite enclosed in the feldspars.

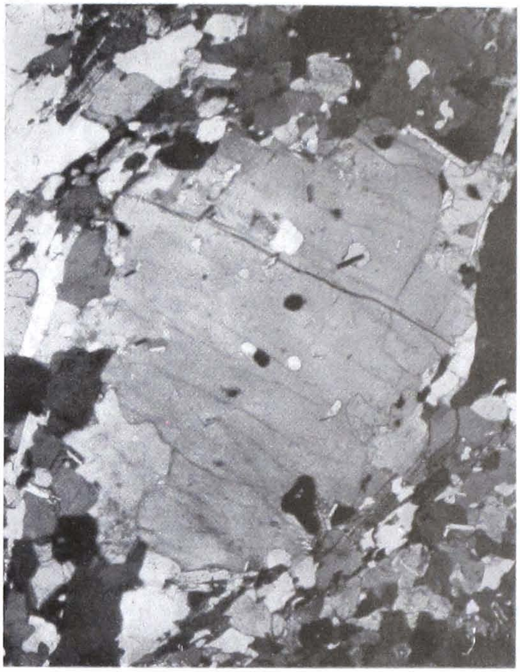

Fig. 1

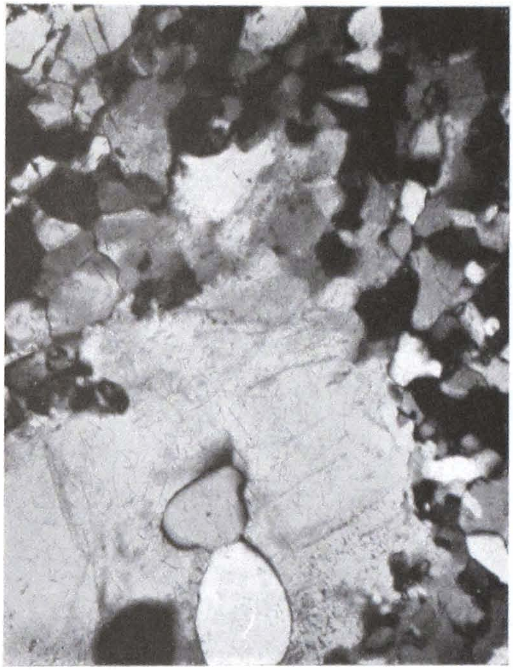

Fig. 2

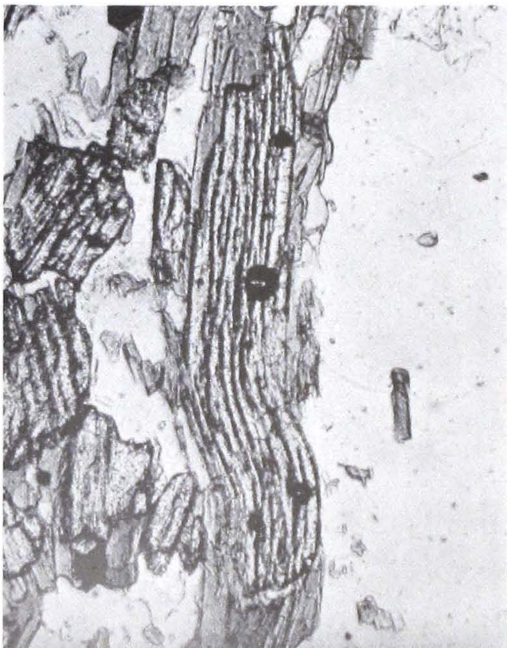

Fig. 3

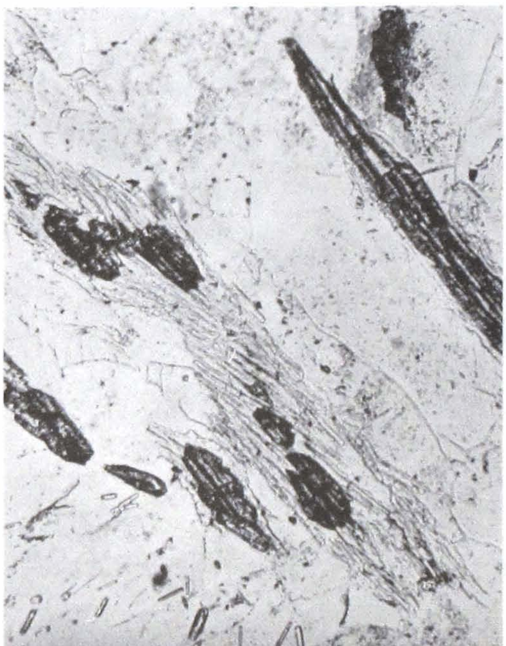

Fig. 4

PLATE 5

THE ROCKS OF THE TWAR BASIC MASS

Fig. 1 and 2. - *Hypersthene diorite.* - *Between Twar and Steriko* (54PZ-21). (Plane polarized light; Fig. 1: × 24; Fig. 2: × 34).
Orthorhombic pyroxene (hypersthene), monoclinic pyroxene, hornblende and biotite are alway associated. Note the lack of idiomorphism of the femic minerals. Fig. 2 shows a regular association of orthorhombic and monoclinic pyroxene; the last is succeeded, at the borders, by hornblende. Large ore granules are common.

» 3. - *Hypersthene diorite.* - *Between Twar and Steriko* (54PZ-21). (Crossed nicols; × 24).
Twinned plagioclases characterized by uniform composition (andesine 40-50 % An) and by broad twinning lamellae. All the plagioclases are idiomorphic.

» 4. - *Hypersthene diorite.* - *Above Steriko* (54PZ-63). (Crossed nicols; × 24).
Plagioclases, with the same characters shown in fig. 3. but with preferred orientation. This parallel texture is very common.

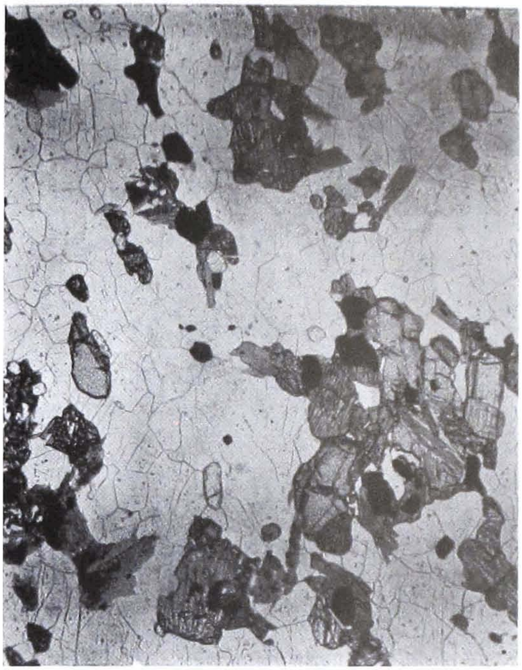

Fig. 1

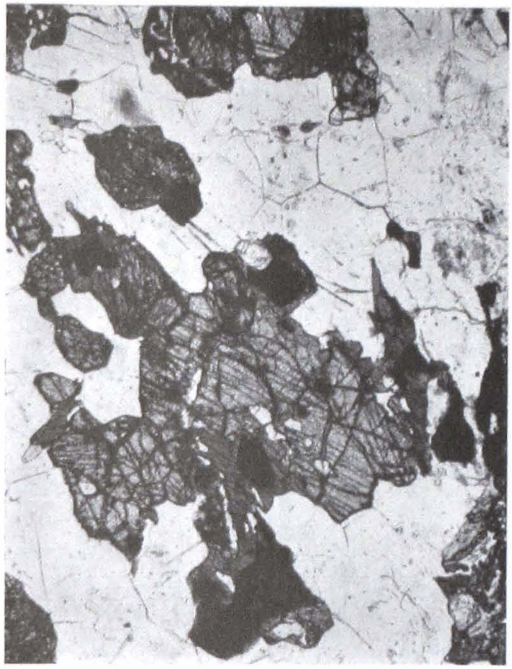

Fig. 2

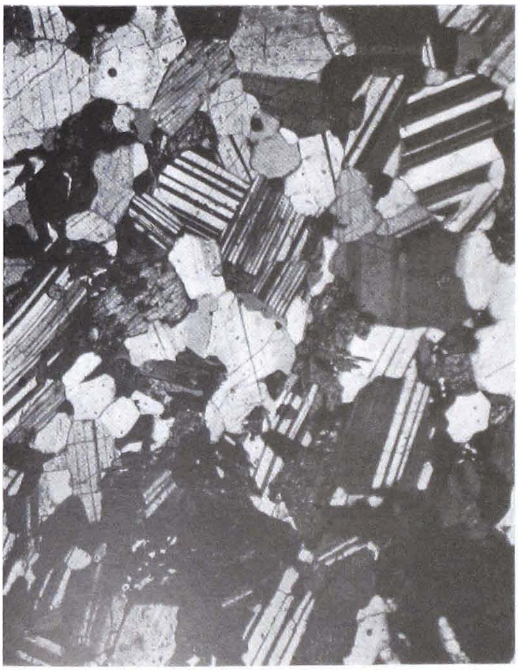

Fig. 3

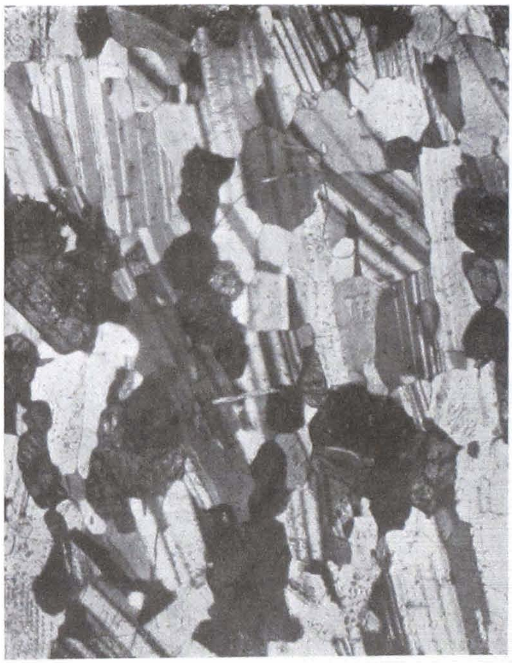

Fig. 4

PLATE 6

THE ROCKS OF THE TWAR BASIC MASS

Fig. 1. - *Biotite-amphibole-pyroxene diorite.* - *Between Twar and Steriko* (54PZ-61). (Plane polarized light; × 44).
Hornblende and biotite are much more common than the pyroxene. Note the large size of the biotite flakes and the tendency to the poikiloblastesis of the amphibole crystals.

» 2. - *Hypersthene diorite.* - *Above Steriko* (54PZ-63). Plane polarized light; × 46).
Hypersthene crystals rich in reddish lamellar inclusions regularly disposed in the pyroxenic host.

» 3. - *Tonalite with pyroxene. In the canyon, to the east of Twar* (54PZ-65). (Crossed nicols; × 30).
Large microperthitic patch enclosing plagioclases (andesine 40-50 % An) and femic minerals. The plagioclases are more or less completely replaced. It is interesting to observe that the hornblende is particularly poikiloblastic inside the microperthitic patch.

» 4. - *Hypersthene diorite.* - *Between Twar and Steriko* (54PZ-21). (Plane polarized light; × 82).
Biotite crystalloblasts in a fanlike arrangement; the mica flakes become clearly poikiloblastic at their extremity.

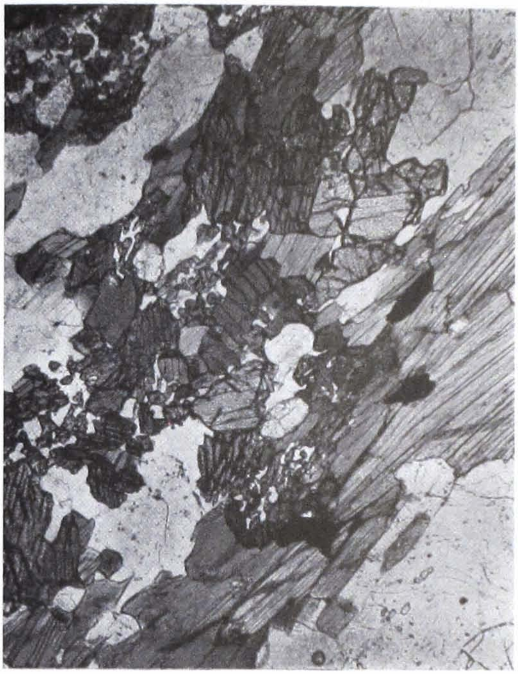
Fig. 1


Fig. 2

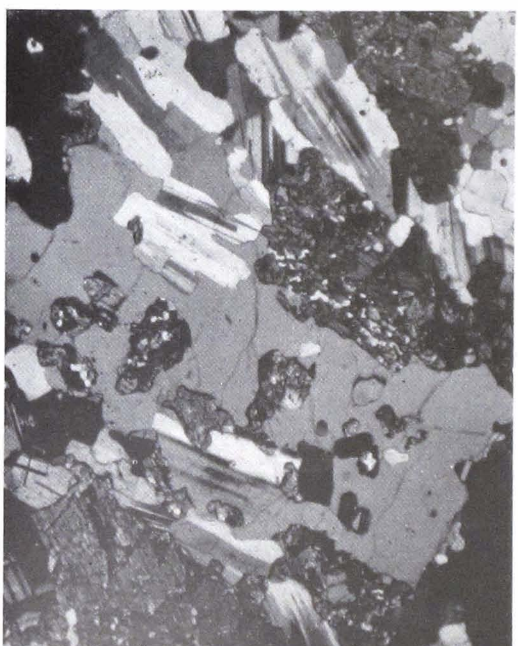
Fig. 3

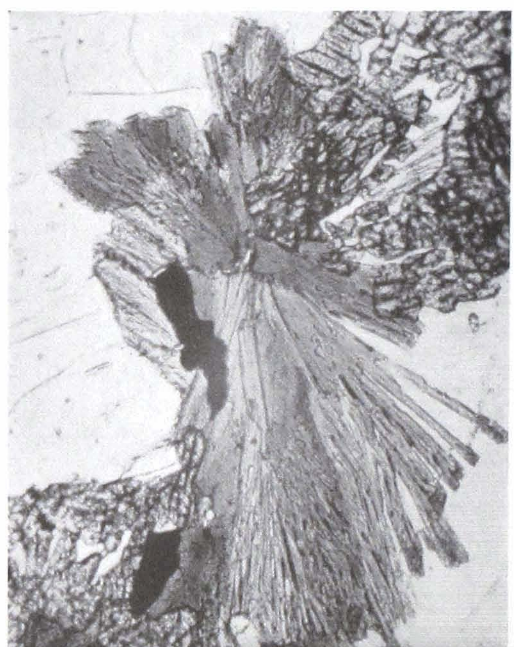
Fig. 4

Plate 7

THE ROCKS OF THE TWAR BASIC MASS

Fig. 1. - *Amphibole-biotite diorite. - Between lower and middle Steriko* (54PZ-62). (Plane polarized light; × 26).
Amphibole-biotite association. The hornblende crystals are clearly poikiloblastic, particularly in the central portions; the outer portions sometimes show a certain continuity.

» 2. - *Amphibole-biotite diorite. - Between lower and middle Steriko* (54PZ-62). (Plane polarized light; × 50).
Hornblende poikiloblast (in detail).

» 3 and 4. - *Amphibole-biotite-scapolite hornfels enclosed in the meta-diorite. - Near Steriko* (54PZ-24b). (Crossed nicols, Fig. 3: × 21; Fig. 4: × 78).
Large crystals of scapolite (mizzonite), recognizable by the typical wrinkled surfaces, develop in the rock, enclosing biotite and amphibole.

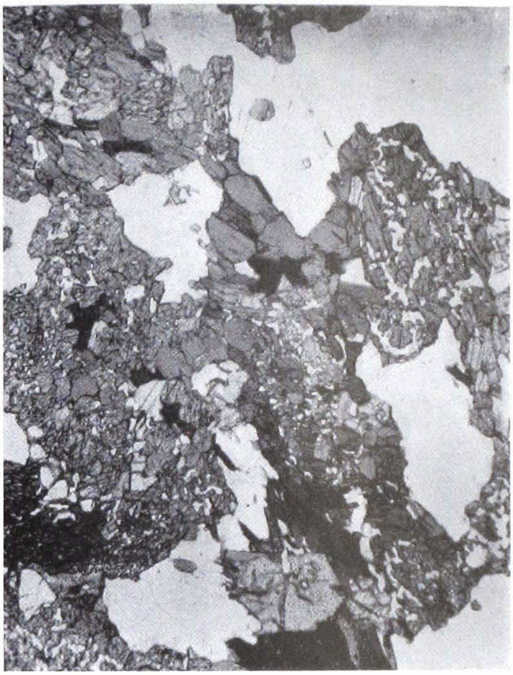

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Plate 8

THE SKOYO-TURMIK PLAGIOCLASE GNEISSES

Fig. 1. - *Plagioclase gneiss with biotite and epidote. - To the west of Dasu* (54PZ-17). (Plane polarized light; × 45).
Crystals of muscovite, epidote and biotite enclosed in a plagioclasic porphyroblast (14-20 % An). Sometimes the enclosed minerals are quite abundant.

» 2. - *Plagioclase gneiss with biotite, epidote and amphibole. - Western part of the mass, at the height of 3900 m (12.800 ft)* (54PZ-75). (Crossed nicols; × 29).
Between two plagioclase porphyroblasts, belonging to a plagioclasic patch, a streak of quartz, epidote, biotite and plagioclasic granoblasts is inserted. Among the minerals enclosed in the plagioclasic porphyroblasts the horneblende is recognizable too.

» 3. - *Plagioclase gneiss with biotite and epidote. - At the eastern contact of the mass, on the right side of the Turmik valley* (54PZ-92). (Crossed nicols; × 70).
Many quartz granules are enclosed in the outer parts of a plagioclasic porphyroblast.

» 4. - *Plagioclase gneiss with biotite and epidote. - To the west of Dasu* (54PZ-17). (Crossed nicols; × 30).
Muscovite flakes and small crystals of epidote disposed according to the composition planes of twinning and to the planes of cleavage of the plagioclasic host.

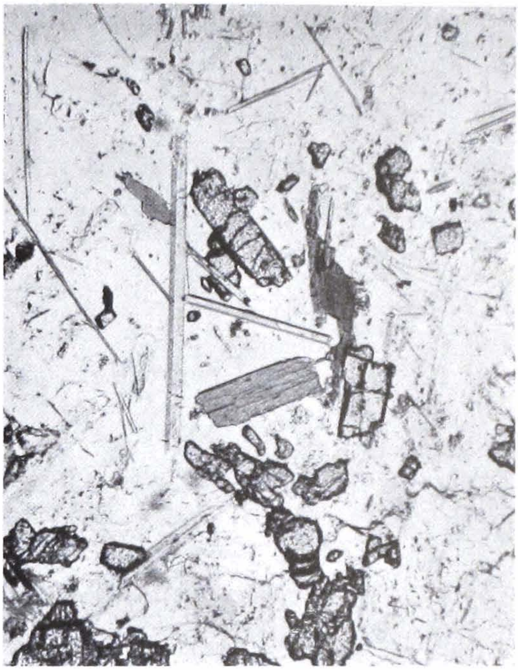

Fig. 1

Fig. 2

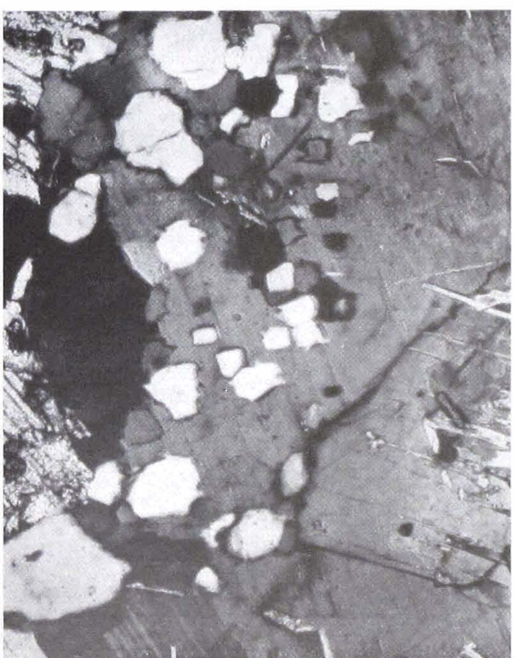

Fig. 3

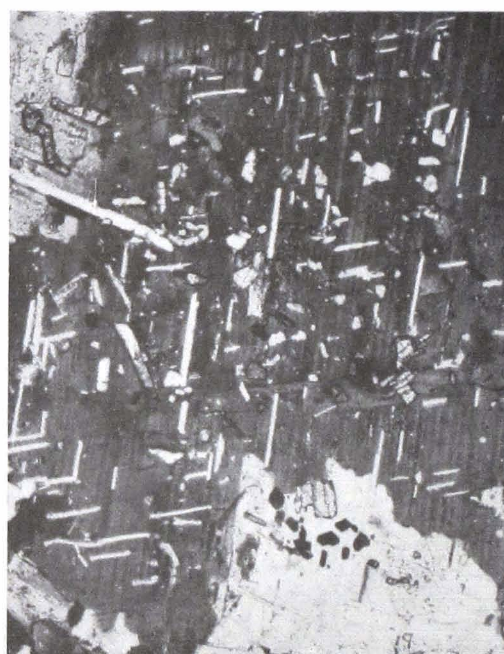

Fig. 4

Plate 9

THE SKOYO-TURMIK PLAGIOCLASE GNEISSES

Fig. 1. - *Plagioclase gneiss with biotite, epidote and amphibole.* - *Western part of the mass, at a height of 3900 m (12.800 ft)* (54PZ-75a). (Crossed nicols; × 30).
In a granoblastic matrix formed by plagioclase and quartz, and enclosing biotite, epidote, muscovite and amphibole, many contiguous plagioclasic granoblasts attain, by recrystallization, the same orientation. Plagioclasic porphyroblasts, plenty of particles of quartz, biotite, epidote, muscovite and amphibole are growing, in this way, in the matrix.

» 2. - *Plagioclase gneiss with biotite and epidote.* - *To the west of Dasu* (54PZ-17). (Crossed nicols; × 80).
Biotite crystalloblasts enclosed in the plagioclasic porphyroblasts and gradually replaced. Before disappearing, the biotite loses its pleochroism and is converted to light mica.

» 4. - *Plagioclase gneiss with biotite, epidote and amphibole.* - *Western part of the mass, at te height of 3900 m (12.800 ft)* (54PZ-75). (Plane polarized light; × 70).
Plagioclasic porphyroblasts enclosing crystalloblasts of biotite and amphibole, besides epidote and muscovite. The figure shows a stage of the progressive transformation of the biotite and hornblende.

» 3. - *Plagioclase gneiss with biotite and epidote.* - *At the eastern contact of the mass, on the right side of the Turmik valley* (54PZ-92). (Crossed nicols; × 55).
A large poikiloblast of muscovite which crosses, uninterrupted, an oligoclase porphyroblast and the granoblasts of quartz and plagioclase of the matrix.

Fig. 1

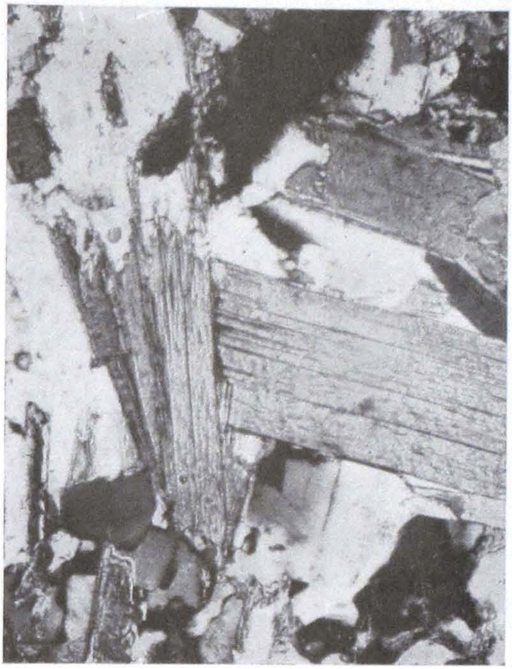

Fig. 2

Fig. 3

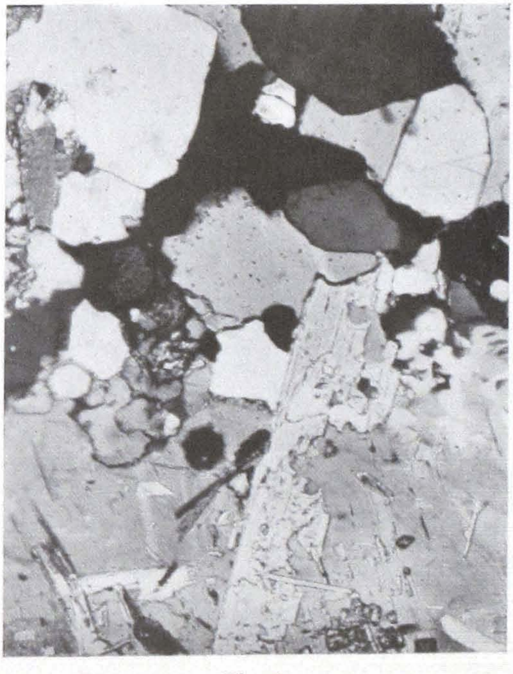

Fig. 4

PLATE 10

THE SKOYO-TURMIK PLAGIOCLASE GNEISSES

Fig. 1. - *Plagioclase gneiss with biotite and epidote. - To the west of Dasu* (54PZ-17). (Crossed nicols; × 35).
Wavy extinction of large crystalloblasts of quartz.

» 2 and 3. - *Plagioclase gneiss with biotite and epidote. - To the west of Dasu* (54PZ-17). (Figs. 2 and 3: Crossed nicols; × 90).
Quartz granules enclosed in plagioclasic porphyroblasts. Note that the borders cutting the composition planes of the twinned plagioclases have a zig-zag form. Moreover, around the inclusions of quartz the plagioclase shown higher birefringence.

» 4. - *Plagioclase gneiss with biotite and epidote. - To the west of Dasu* (54PZ-17). (Crossed nicols; × 66).
Plagioclasic patch enclosing crystals of quartz, biotite, epidote and muscovite. The plagioclase of this patch is not homogeneous (see the lower right side of the figure), but it is formed by many granoblasts; between each granoblast and the contiguous ones the optical orientation varies little.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Plate 11

THE SKOYO-TURMIK PLAGIOCLASE GNEISSES

Fig. 1 - *Biotite-epidote gneiss. - To the west of Dasu* (54PZ-17a). (Crossed nicols; × 24).
The rock is formed by an aggregate of quartz, sodic plagioclase (albite-oligoclase 10 % An), biotite and epidote. The biotite is present with equidimensional flakes, regularly distributed and orientated according to the schistosity of the rock. Larger poikiloblasts of muscovite develop in cross-wise direction to the schistosity.

» 2 and 3. - *Biotite-epidote gneiss with plagioclasic porphyroblasts. - To the west of Dasu* (54PZ-16). (Figs. 2 and 3: crossed nicols; × 24).
The matrix of this rock is similar to the biotite-epidote gneiss shown in fig. 1, but the biotite is scarcer and the schistosity, though clear, is less pronounced. The plagioclasic porphyroblasts (oligoclase-albite) which develop in this matrix, enclose many small particles of the matrix minerals; they are analogous to the porphyroblasts of the plagioclase gneisses.

» 4. - *Plagioclase gneiss with biotite and epidote. - At the eastern contact of the mass, in the Turmik valley* (54PZ-92). (Crossed nicols; × 24).
In this typical plagioclase gneiss are visible either patches, formed by small granoblasts (similar to the matrix of the rocks represented in figs. 2 and 3), or plagioclasic porphyroblasts (similar to the porphyroblasts of te rocks represented in figs. 2 and 3). In this rock, however, the recrystallization is much more advanced, as one can see by the dimensions of the biotitic flakes.

Fig. 1

Fig. 2

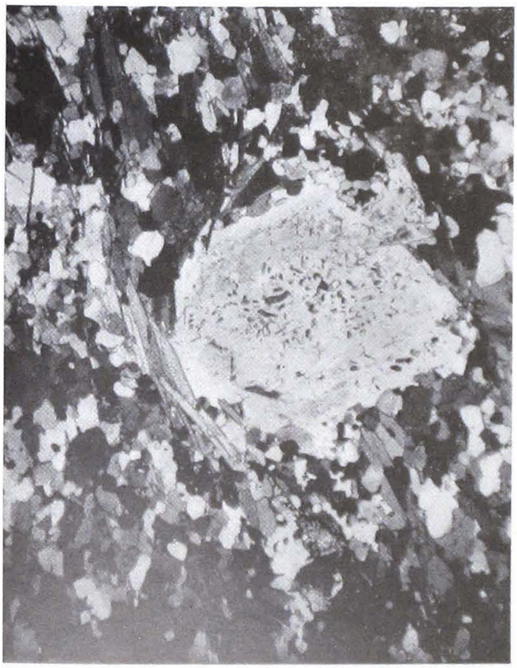

Fig. 3

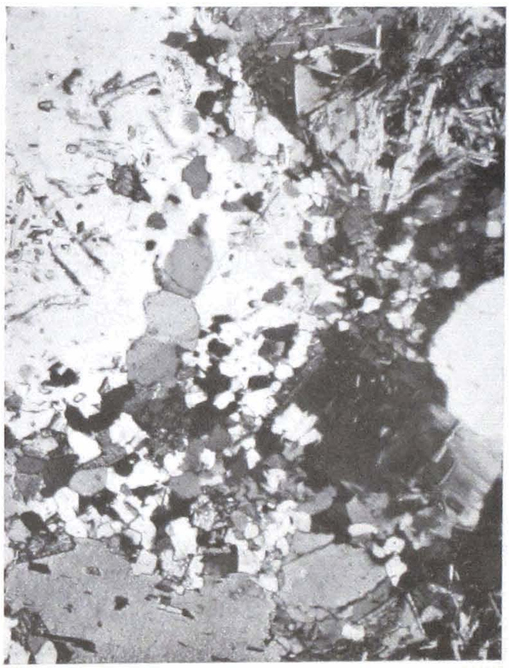

Fig. 4

Plate 12

THE ROCKS OF THE INDUS VALLEY, ABOVE THE CONFLUENCE WITH THE TURMIK VALLEY

Fig. 1. - *Labradorite-biotite-sillimanite gneiss rich in garnet. - Near the Katzarah lake (Forok Tso)* (54PZ-1). (Plane polarized light; × 26).
The matrix of the rock is formed by an aggregate of quartz and of labradorite-bytownite. Abundant sillimanite forms at the expense of biotite.

» 2. - *Augite-horneblende-biotite gabbrodiorite. - Near the elbow of the Indus river, opposite the village of Basha* (54PZ-4). (Plane polarized light; × 42).
Parallel growth of hornblende on augite.

» 3. - *Hypersthene diorite. - Near Tungas* (54PZ-11). (Plane polarized light; × 40).
Large flakes of biotite enclose small pyroxenic crystals. Pyroxene and biotite are separated by a border of amphibole.

» 4. - *Hypersthene diorite. - Near Tungas* (54PZ-11). (Crossed nicols; × 80).
Andesine crystals enclosing thin acicular mineral with preferred orientation.

Fig. 1

Fig. 2

Fig. 3

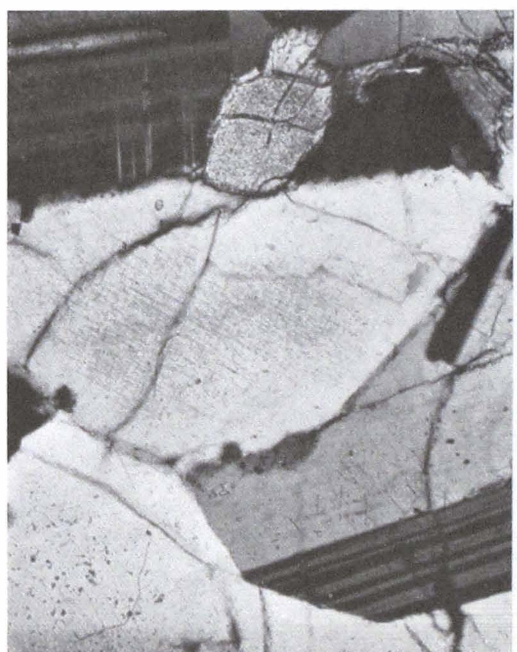

Fig. 4

Plate 13

THE ROCKS OF THE AMPHIBOLITIC CRETACEOUS FORMATION: THE MOST COMMON TYPES

Fig. 1. - *Amphibolite. - The Turmik valley* (54PZ-97). (Plane polarized light; × 26).
The prevalent mineral is the hornblende, present with very elongated crystals. The plagioclase is confined to thin lenses or bands.

» 2. - *Epidote amphibolite. - The Indus valley at a height of 3370 m (11.000 ft), above Mulakor* (54PZ-70). (Plane polarized light; × 30).
Hornblende and epidote are present in the same quantity. The epidote is represented either by clinozoisite or by pistacite.

» 3. - *Garnetiferous amphibolite. - The Turmik valley, below the Stak-la* (53PD-19). (Plane polarized light; × 36).
Besides hornblende and plagioclase (oligoclase-andesine), porphyroblasts of garnet are present. The schistose texture in this rock is less pronounced than in the amphibolites of lower metamorphic grade.

» 4. - *Biotite gneiss. - To the west of the Skoyo-Turmik mass, at a height of 3800 m (12,500 ft)* (54PZ-73). (Plane polarized light; × 30).
The mineralogical assemblage is formed by oligoclase and biotite. Besides these minerals, minor quantities of muscovite are present; it forms poikiloblasts often disposed in cross-wise direction to the schistosity of the rock.

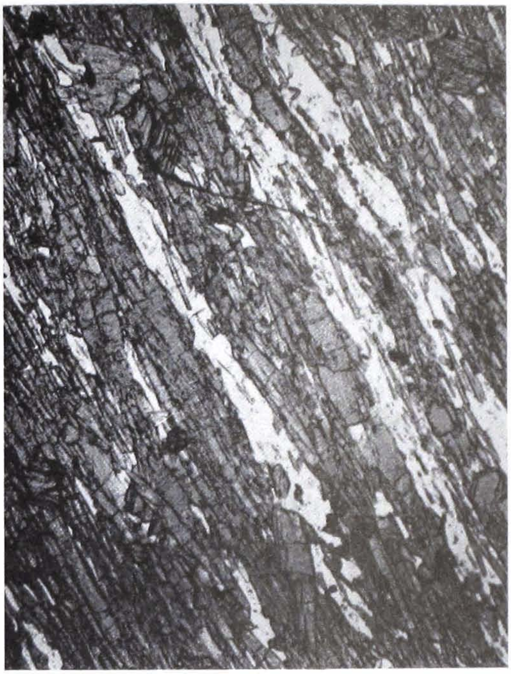

Fig. 1

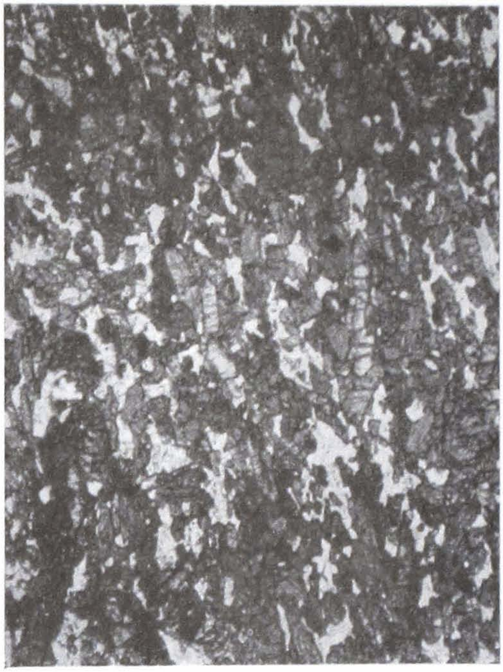

Fig. 2

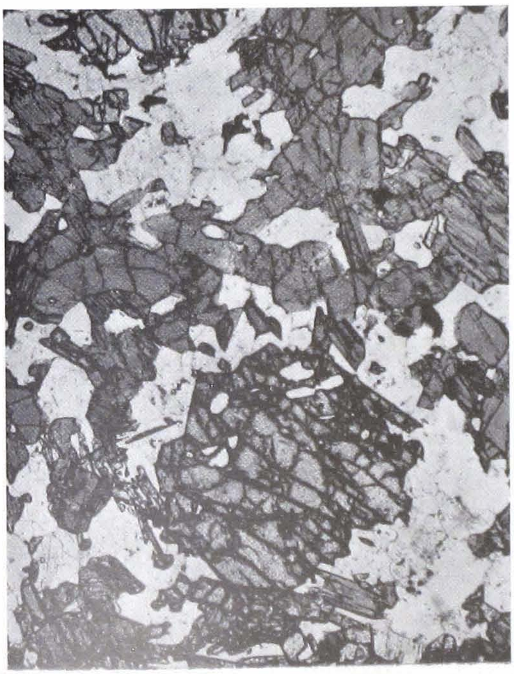

Fig. 3

Fig. 4

Plate 14

THE ROCKS OF THE AMPHIBOLITIC CRETACEOUS FORMATION : SPECIAL TYPES

Fig. 1. - *Actinolite schists rich in micaceous porphyroblasts. - The Turmik valley, to the west of Dasu* (54PZ-80). (Crossed nicols; × 24).
Large poikiloblasts of phengite are developed in a fine-grained matrix formed essentially of acicular actinolite.

» 2. - *Actinolite-epidote schist rich in chlorite porphyroblasts. - The Turmik valley, to the west of Dasu* (54PZ-95). (Crossed nicols; × 70).
Porphyroblasts of clinochlore develop in a fine-grained matrix, formed of actinolite and epidote.

» 3. - *Serpentinite. - Lower part of te Turmik valley, to the north of Dasu* (54PZ-90). (Croissed nicols; × 70).
In a fine-grained serpentine matrix patches formed of the union of more developed crystals of fibrous serpentine are present. In the core of these crystals, talc is often found.

» 4. - *Porphyroblasts of carbonate in arenaceous phyllite. - Left side of the Turmik valley, to the north of Kushumal* (54PZ-110). (Crossed nicols; × 24).
Large rhombohedral crystals of carbonate develop in the matrix of an arenaceous phyllite, pushing away the quartzose-micaceous bands. These porphyroblasts enclose many minerals of the matrix (the enclosed granules of quartz are easily recognizable).

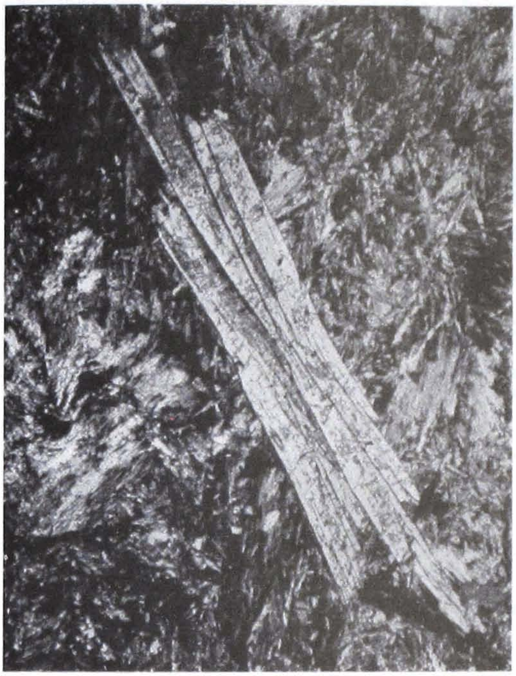

Fig. 1

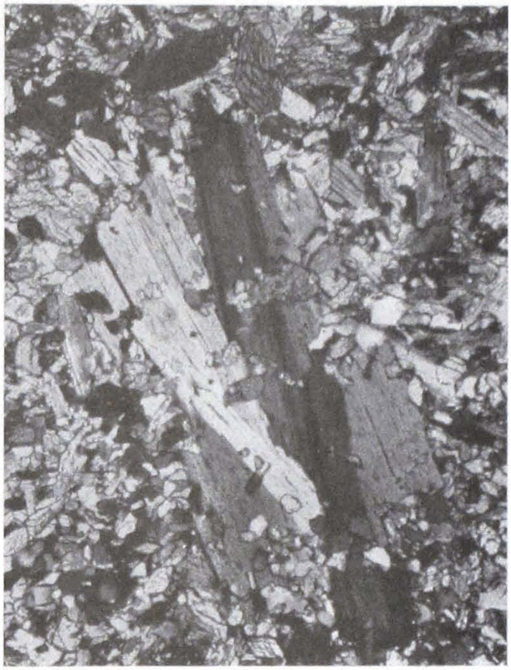

Fig. 2

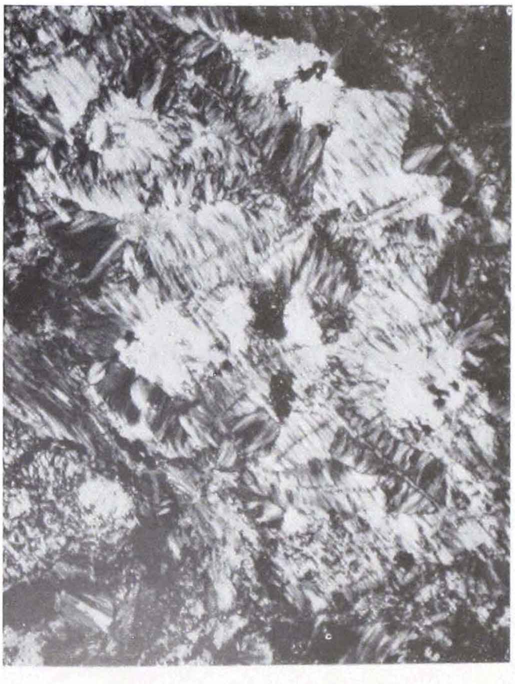

Fig. 3

Fig. 4

Plate 15

THE ROCKS OF THE RIGHT SIDE OF THE SHIGAR VALLEY: TONALITES AND GABBRODIORITES

Fig. 1. - *Cataclastic tonalite.* - *Near Tisar* (54PZ-130). (Crossed nicols; × 24).
Idiomorphism of the plagioclase crystals (oligoclase-andesine). In the central parts they are partially weathered.

» 2. - *Cataclastic tonalite.* - *Near Tisar* (54PZ-130). (Crossed nicols; × 26).
The figure shows the sodic shell (albite-oligoclase) enveloping the idiomorphic plagioclase crystals (oligoclase-andesine). Note at the center of the figure a plagioclase xenoblast (albite-oligoclase) thinly and irregularly twinned.

» 3. - *Gabbrodiorite.* - *Between Pendo and Bhundo* (54PZ-270). (Crossed nicols; × 70).
The rock is formed of amphibole and of slightly zoned plagioclase (average composition = andesine 40 % An), which irregularly replaces the central portions, much richer in An (70 % An).

» 4. - *Diorite.* - *To the south of Nielle* (54PZ-281a). (Plane polarized light; × 24).
Hornblende poikiloblasts of the dioritic rock in direct contact with carbonatic rocks, converted to calc-silicate hornfels.

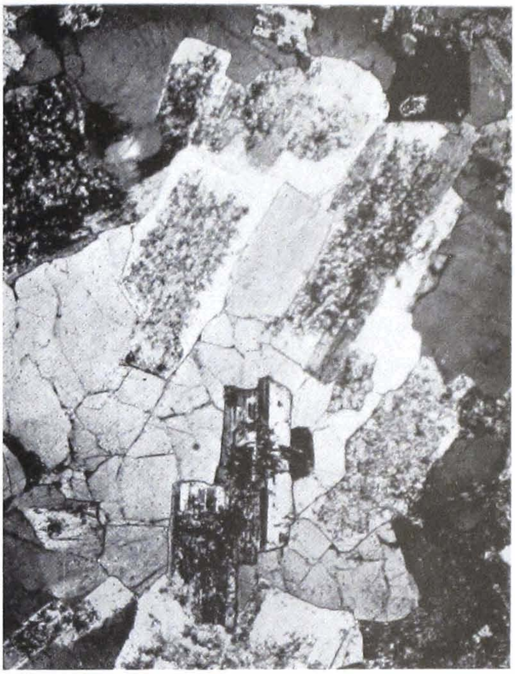

Fig. 1

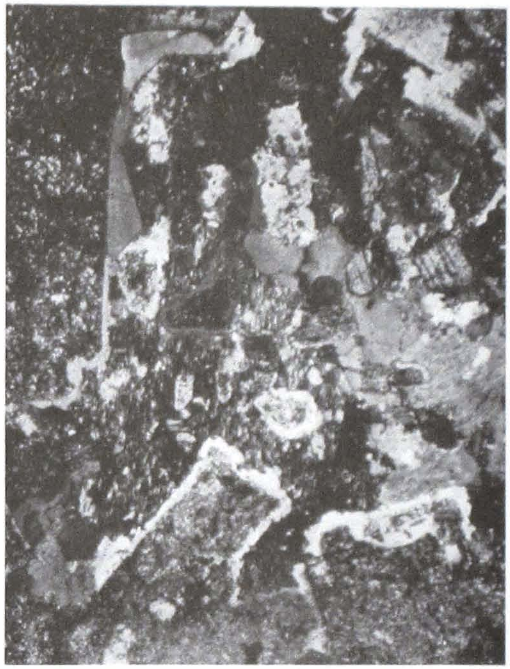

Fig. 2

Fig. 3

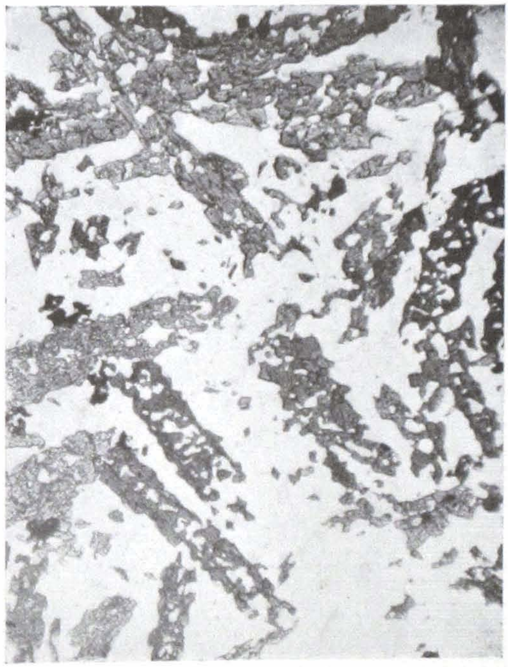

Fig. 4

Plate 16

THE ROCKS OF THE RIGHT SIDE OF THE SHIGAR VALLEY: THE ROCKS AFFECTED BY THERMAL METAMORPHISM

Fig. 1. - *Biotite-andalusite spotted slate. - To the north of Matulu* (54PZ-271). (Crossed nicols; × 26).
Schistose layers of the matrix (quartz, plagioclases, muscovite) pushed away by the growth of andalusite poikiloblasts. The crystalloblasts of biotite are also rather well developed.

» 2. - *Biotite-andalusite spotted slate. - To the north of Matulu* (54PZ-271). (Crossed nicols; × 70).
The andalusite porphyroblasts are extremely poikiloblastic and enclose many small granules of quartz.

» 3. - *Pyroxene hornfels. - Between Matulu and Pendo* (54PZ-273). (Crossed nicols; × 70).
Large poikiloblasts of diopside grow in a rock of calcareous-argillaceous origin by action of thermal metamorphism.

» 4. - *Lenses of wollastonite-diopside-epidote hornfels enclosed in a biotitic-arenaceous schist. - Between Pendo and Bhundo* (54PZ-279). (Crossed nicols; × 24).
The difference of grain size between the portion of rock formed by Ca-Mg silicate and the biotitic-arenaceous portion is clear. It should be noted that near the Ca-Mg silicate hornfelsic lens the minerals of the arenaceous schist have also a coarser grain, an effect of a more advanced recrystallisation.

Fig. 1

Fig. 2

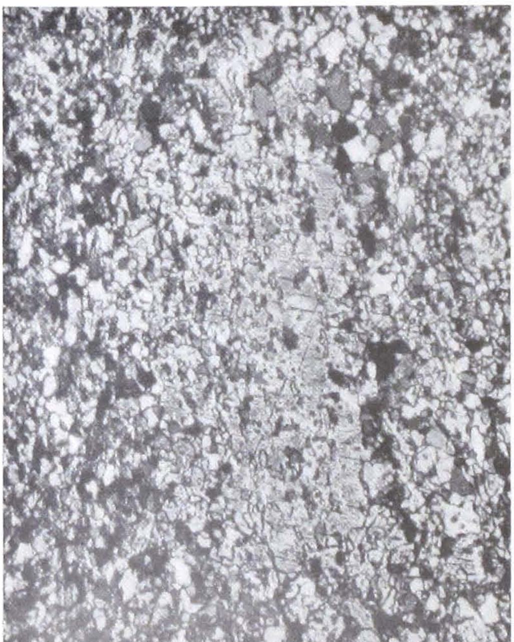

Fig. 3

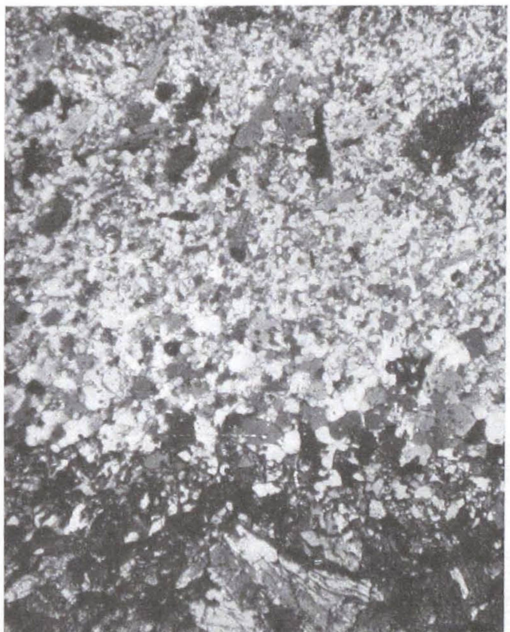

Fig. 4

PLATE 17

THE ROCKS OF THE RIGHT SIDE OF THE SHIGAR VALLEY: THE PLAGIOCLASE GNEISSES

Fig. 1 and 2. - *Biotite-epidote fine-grained amphibolite rich in plagioclase porphyroblasts.* - *Near Kaiyu* (54PZ-265). (Crossed nicols; fig. 1: × 70; fig. 2: × 24).
The albite-oligoclase porphyroblasts enclose many minerals of the matrix: biotite, epidote and also amphibole. Their growth caused the displacement of the matrix minerals.

» 3. - *Plagioclase gneiss.* - *Near Kaiyu* (54PZ-266). (Crossed nicols; × 70).
Oligoclase porphyroblasts slightly zoned; a hornblende crystal enclosed in the central part of this is completely converted to epidote on its rim. In the outer parts of the plagioclase porphyroblast crystalloblasts of biotite are enclosed.

» 4. - *Plagioclase gneiss rich in epidote.* - *Near Kaiyu* (54PZ-268). (Crossed nicols; × 70).
Albite-oligoclase porphyroblasts enclosing many crystals of muscovite and epidote and rare individuals of amphibole. Muscovite and epidote are placed on definite planes of the plagioclasic host.

Fig. 1

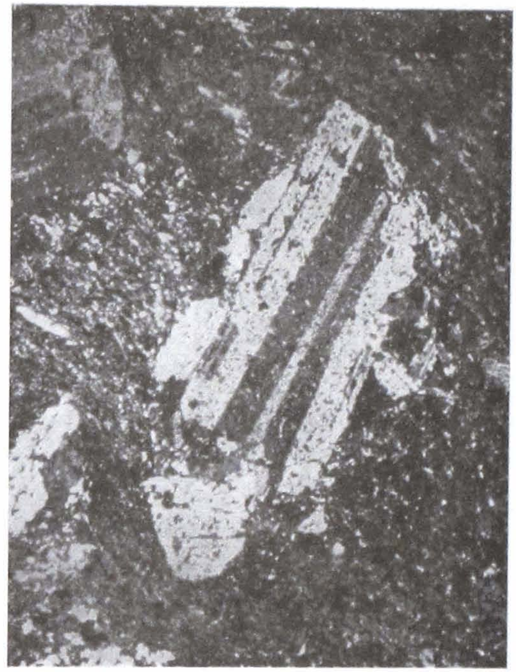

Fig. 2

Fig. 3

Fig. 4

PLATE 18

THE ROCKS OF THE RIGHT SIDE OF THE SHIGAR VALLEY: THE GRANITIC GNEISSES

Fig. 1. - *Granitic mylonitic gneiss. - Between Kaiyu and Yonkil* (54PZ-269). (Crossed nicols; × 20).
Large porphyroblast of microcline enclosing quartz granules, mica flakes and small crystals of plagioclase.

» 2. - *Granitic gneiss. - Between Pendo and Bhundo* (54PZ-278). (Crossed nicols; × 70).
Microcline porphyroblast encloses and replaces plagioclases which, in their turn, enclose poikiloblasts of muscovite.

» 3. - *Granitic mylonitic gneiss. - Between Kaiyu and Yonskil* (54PZ-269). (Crossed nicols; × 70).
Plagioclase (recognizable for its slight polisynthetic twinning) irregularly replaced by K-feldspar. Myrmekite is formed locally.

» 4. - *Granitic gneiss. - Between Pendo and Bhundo* (54PZ-278). (Crossed nicols; × 70).
A flake of biotite enclosed in plagioclasic porphyroblasts is converting to a very poikiloblastic muscovite.

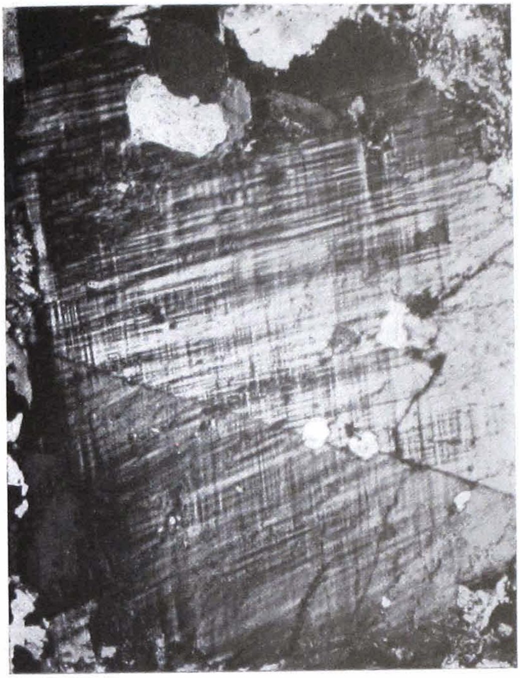

Fig. 1

Fig. 2

Fig. 3

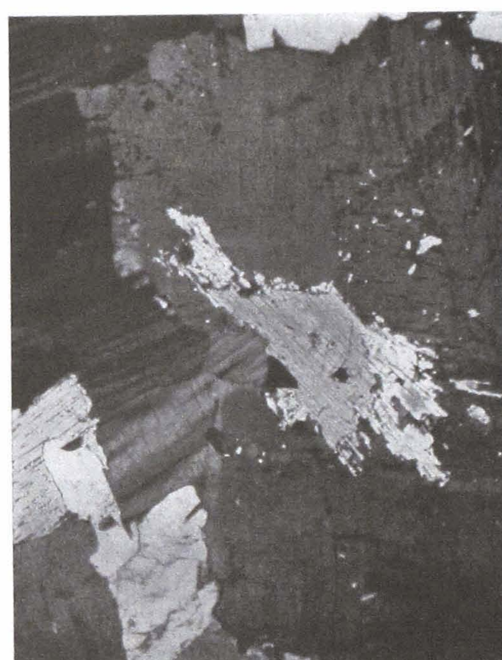

Fig. 4

Plate 19

THE ROCKS OF THE LEFT SIDE OF THE SHIGAR VALLEY

Fig. 1. - *Labradorite gneiss rich in biotite and garnet. - Between Shigar and the mouth of the Skoro Lungma* (54PZ-237). (Crossed nicols; × 24).
Large poikiloblastic flakes of biotite, placed in cross-wise direction to the schistosity of the rock, develop in a matrix formed by labradorite, quartz, muscovite and biotite.

» 2. - *Labradorite-biotite-hornblende gneiss. - Near the mouth of the Bauma-harel Lungma* (54PZ-245). (Plane polarized light; × 24).
In these rocks large crystals of hornblende join with the biotite, while the garnet is absent.

» 3. - *Serpentine schist. - Bauma-harel Lungma* (54PZ-244). (Crossed nicols; × 26).
In a matrix of serpentine, crystals of augite, escaped to the general alteration of the rock, are prominent.

» 4. - *Actinolite schist. - Bauma-harel Lungma* (54PZ-247). (Crossed nicols; × 75).
Crystals of hornblende and augite, only partially altered, are prominent in a matrix formed by small needles of actinolite, originated by alteration of a basic rock, of probable tuffaceous nature.

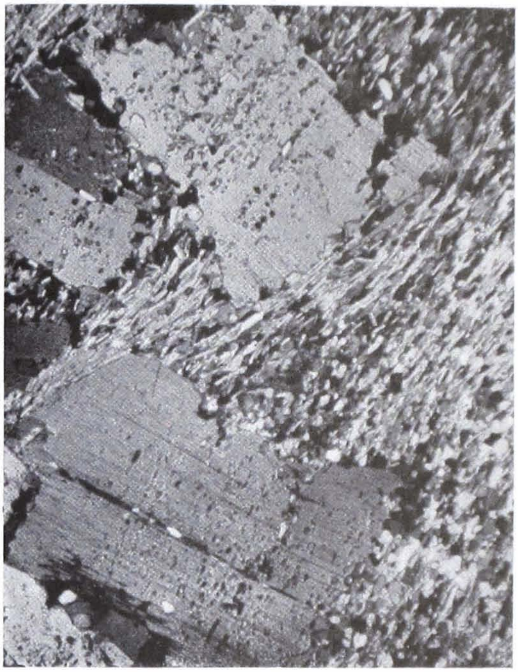

Fig. 1

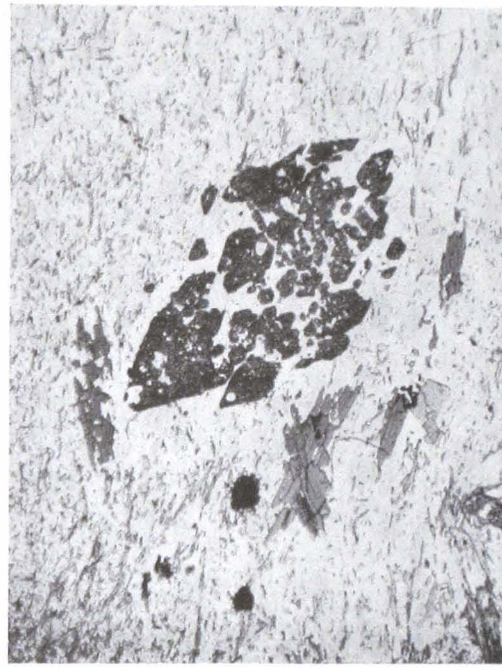

Fig. 2

Fig. 3

Fig. 4

Plate 20

THE ROCKS OF THE LEFT SIDE OF THE SHIGAR VALLEY

Fig. 1. - *Marble rich in tremolite.* - *Between Alchori and Sildi* (54PZ-259). (Crossed nicols; × 26).
Acicular crystals of tremolite, in a sheaplike arrangement, associated with flakes of biotite, form patches and lenses inside the marble.

» 2. - *Graphitic slate.* - *Skoro Lungma* (54PZ-236). (Crossed nicols; × 24).
In the rock, formed by a fine-grained association of sericite, quartz, chlorite and sodic plagioclase, the graphitic streaks are evident.

Fig. 3 and 4. - *Graphitic garnetiferous micaschist.* - *Northern portion of the Shigar valley* (54PZ-258). (Figs. 3 and 4: Crossed nicols; × 70).
Albite porphyroblasts developing in the thinly folded muscovitic layers. It is to be noted that the graphitic trains cross the albitic crystals without changing their direction.

Fig 1

Fig. 2

Fig. 3

Fig. 4

Plate 21

THE ROCKS OF THE LEFT SIDE OF THE SHIGAR VALLEY

Fig. 1. - *Arenaceous phyllite. - Middle-upper section of the Skoro Lungma* (54PZ-235). (Crossed nicols; × 75).
Phyllitic bands, rich in sericite. These bands are alternated with thin layers of arenaceous quartzites.

» 2. - *Arenaceous phyllite. - Skoro-la glacier* (54PZ-229). (Crossed nicols; × 24).
In the fine-grained matrix porhyroblasts of albitic plagioclase are growing, which enclose muscovite and calcite.

» 3. - *Quartz-biotite gneiss. - Near Skoro Katza* (54PZ-232). (Crossed nicols; × 26).
In this rock are distinguishable coarse-grained portions of quartz and fine-grained portions, in which the plagioclase porphyroblasts generally develop.

» 4. - *Quartz-biotite gneiss. - Near Skoro Katza* (54PZ-232). (Crossed nicols; × 75). (Enlargment of a detail in fig. 3).
The plagioclase (albite-oligoclase), growing in the fine-grained sericitic portions, does not possess clear boundaries and ecloses many small crystals of sericite and epidote.

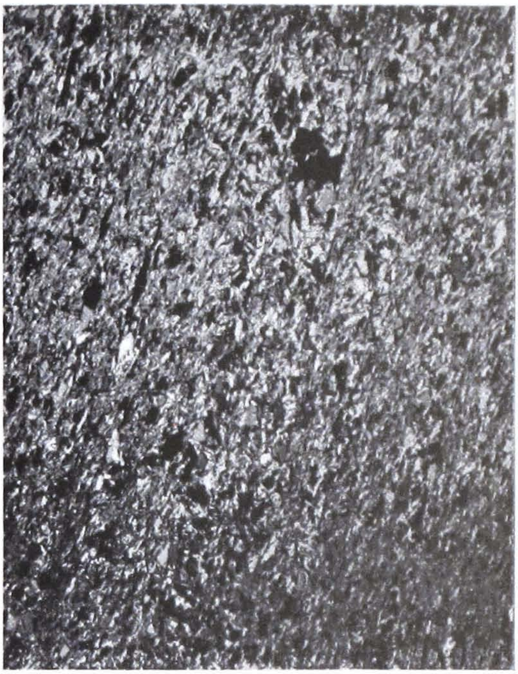

Fig. 1

Fig. 2

Fig. 3

Fig. 4

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Sancasciano Val di Pesa (Firenze)
— Novembre 1964 —